Transactions of the Seismological Society of Japan.

Vol. XIII., Part I.

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TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY

OF JAPAN.

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CONTENTS.

PART I.

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CONTENTS.

PECULIAR PHENOMENA IN THE PROPAGATION OF EARTHQUAKES.

By Professor Hans Höefer, Leoben, Austria.

(WITH DIAGRAMS.)

[Read October 11th, 1888.]

It has long been a recognized fact and one which has been repeatedly demonstrated, that many of the severer earthquakes, whilst exhibiting in flat districts an area of no mean extent, have soon found a limit to their spreading in the adjacent mountains, notwithstanding that the waves have struck the foot of the mountains with considerable force and have, here and there, even caused the greatest destruction to the base itself or to places in the vicinity. In cases of this nature the mountains have often been likened to a wall which the shocks were powerless to pierce.

In Europe the Alps are regarded as a rampart of this nature against many an earthquake of Upper Italy, and in South America the Andes with their parallel chains are looked upon as forming, in a more especial degree, a wall against the frequent and oft-times intense shocks of the plains of the western coast.

The reason for this peculiar phenomenon has been sought in mighty zones of rejection which the waves are unable to pass, or in which the shocks lose a considerable portion of their intensity; a second explanation is based on the supposition that the seismic energy is insufficient to produce vibrations in such huge mountain masses; and other similar causes have been adduced. Reasons of this kind are either directly refuted by the fact that earthquakes pass in undiminished intensity

intensity will diminish outwards over the plain as well as in the mountains. In the event of $D\ E'\ F$ being the final isoseist, nearly vertical shocks would be felt on the confines of the area of disturbance on the mountain side at J, whereas at the foot of the mountain, and where the intensity would be much greater, lateral vibrations would occur.

This case shows a quite peculiar eccentrical position of the epicentrum L with reference to the isoseists, which would have their centre at B, whereas one is accustomed to seek the epicentrum centrically in the midst of the lines of equal intensity.

It is scarcely necessary to point out that if the epicentrum L be ascertained according to one of the well-known methods, the depth t of the focus can be found with the help of the final curve DEF in manner similar to that adopted in the preceding cases. If $LO = t$, and if $LM = h$ be the relative height of L above AB, and the difference in height of J and $L = h_{,}$, the previous formula will become

$$t = \frac{a^2 - b^2 + h^2 - h_{,}^2}{2\ (h + h_{,})}$$

A fact which has been repeatedly demonstrated in mountainous districts is that an earthquake has been felt in two or more neighbouring parallel valleys, but not on the heights; or that the strength of a shock has been incomparably greater in the valleys than at places situated at a height.

The opposite distribution of intensity is also known.

The explanation of all these phenomena, apparently so replete with contradictions, is in the same way based on the positions of the curves of intensity with respect to the terrestrial formation.

If O (Fig. 4) be the seismic focus and $A\ B\ C$ a curve of intensity, the lower portion of the ground, the portion, that is to say, nearest to O, will vibrate more than that situated above it,—the earthquake will be felt in the valleys D and F more than on the ridge E. If $A\ B\ C$ be the final isoseist to which the shock attains, the places lying higher will not feel a shock

that is very perceptible in the valleys. The term "earthquake-bridge" has been applied to mountain ranges of this kind.

In Fig. 5, *O* lies comparatively near the earth's surface. I. is a curve of greater intensity than that denoted by II., and greater still than that marked III. The summit *E* will, therefore, be affected to a greater extent than the slopes *A* and *B;* in the valleys *D* and *F*, on the other hand, the earthquake may possibly be scarcely perceptible.

Whilst in Fig. 4, the focus *O* is at a greater depth than the centre of a circle passing through the valleys *D* and *F* and the summit *E*, in Fig. 5 the contrary is the case.

A simple geometrical construction gives, with the help of the three points *D*, *E*, and *F*, the radius of the circle corresponding to the profile of the mountain, which permits, therefore, of an estimate being made of the depth of the seismic focus, presuming that the latter lies in the profile plane. With the help of four points of equal earthquake intensity, the geometrical position of the focus can be exactly determined, even where the focus does not fall within the vertical plane of the profile drawn. The problem to be solved runs thus:

"Through four points lay a spherical shell and determine the position of its centre (seismic focus)."

If several spheres of intensity are successfully determined with the help of in each case at least four points, they would necessarily possess, in the case of a central shock, a common centre. On the other hand, the geometrical positions of the centres of the spheres would lie in the case of linear quakes at a substantial distance from each other, and all the more so if the four points are situated at one end and the four others at the opposite end of the extended area of disturbance.

The sources of error unavoidable in the observation of an earthquake can only be eliminated by combining the greatest possible number of most trustworthy statements; none but average values procured in such fashion and controlling each other can form a satisfactory basis for further conclusions.

Leoben, March 1st, 1888.

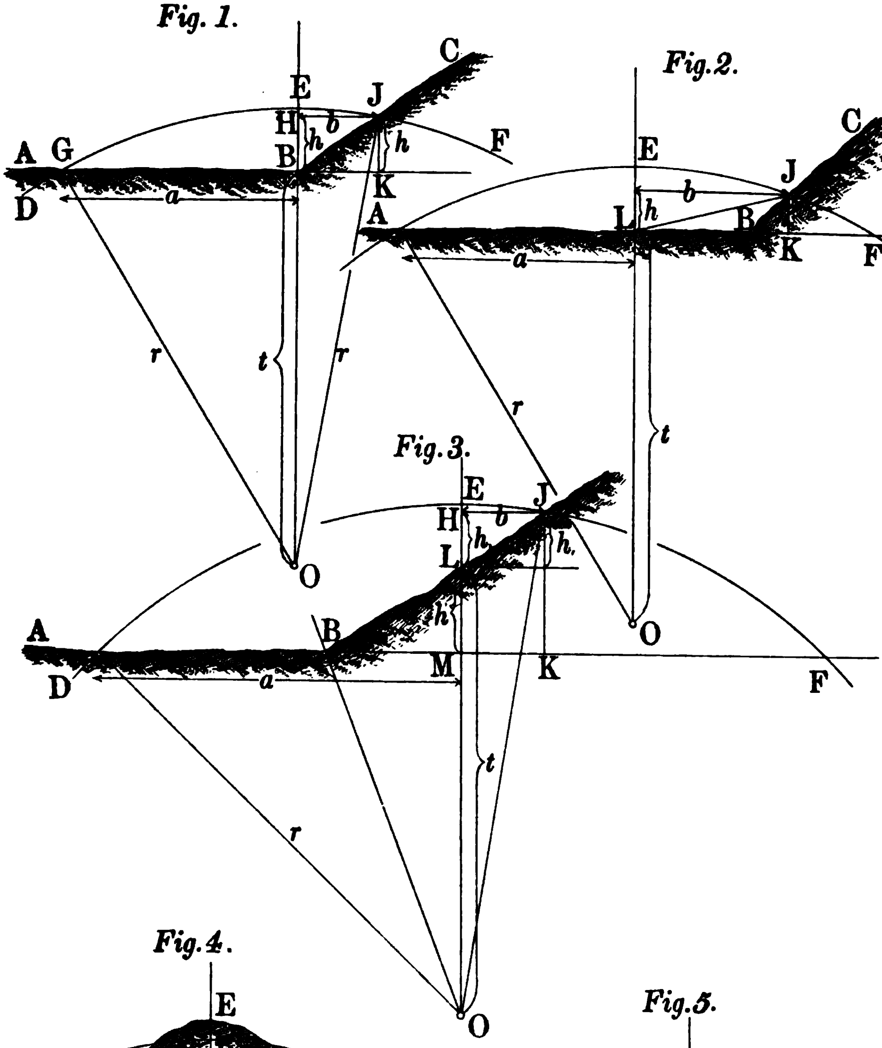


Fig. 1. *Fig. 2.* *Fig. 3.*

Fig. 4.

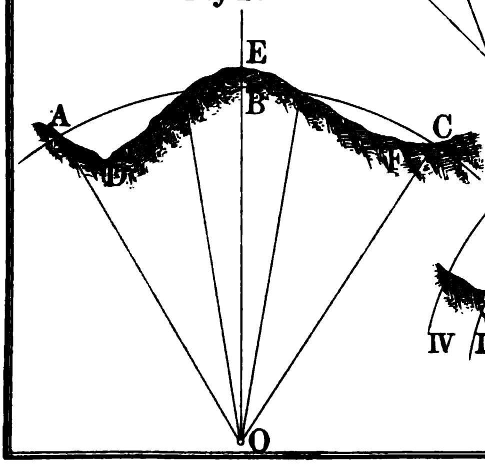
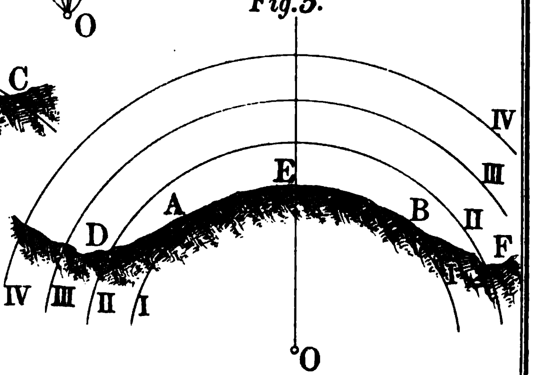


Fig. 5.



EARTH TREMORS IN CENTRAL JAPAN.

(SECOND PAPER.)

By JOHN MILNE.

[Read December 4th, 1888.]

On November 18th, 1886, I read a paper before the Seismological Society on Earth Tremors in Central Japan (see Trans. Seis. Soc., Vol. XI., p. 1-78). In that paper I described the various tremor indicators which I have used in Japan, concluding with a description of an instrument which gave automatically a continuous record of tremors. The records given in this paper were obtained by the same instrument. They extend from December 22nd, 1886, to February, 1888. At certain times owing to my absence from Tokio the instrument was not working. In the following list these dates have been omitted. The tremors are recorded as indicated on two bands of paper, one running N.N.E. and the other running N.N.W. The letter *T* means tremors of considerable magnitude indicated as a line of perforations from 2 to 5 millimeters broad. *ST* means small tremors forming a line from 1 to 2 millimeters broad. *VST* means very small tremors. A. and P., which are usually prefixed by a numeral indicating hours, mean morning or A.M. and afternoon and night or P.M. In the column headed "Wind," *O* means that in Central Japan there was no wind or only a gentle breeze of force 1 in Central Japan, or wind not exceeding force 3 at not more than one place, and this place was not Tokio when the observations were made; *w* means that there was wind of not more than intensity 2, at not more than two places in Central Japan. *W* means that there was wind of force 2 or of greater than 2 at a number of places. WT_3 or WT_4 means that there was a strong wind of force 3 or 4 blowing at Tokio only.

The data referring to wind were obtained from the tri-daily weather maps published by the Meteorological Department of this country, the observations being made at 6 a.m., 2 p.m., and 9 p.m.

The wind intensities are as follows:—

0 = calm	=	0—1.5 meters per second.
1 = light	=	1.5—35 meters per second.
2 = moderate	=	3.5— 6 meters per second.
3 = strong	=	6—10 meters per second.
4 = gale	=	10—15 meters per second.
5 = heavy gale	=	15—29 meters per second.
6 = hurricane	=	29—104 meters per second.

By Central Japan is meant the country within 200 to 300 miles of Tokio in which area there are eleven observing stations telegraphically connected with the capital.

In the column headed "Remarks" reference is made to the height of the barometer expressed in millimeters at Tokio, and the position of the centre of the barometrical depression.

The reason for giving prominence to wind intensity rather than to any other meteorological phenomena will be understood by a perusal of the results of analyses given in my previous paper. These results were as follows:—

1.—Earth tremors are more frequent with a low barometer than with a high barometer, but even with a low barometer it may often happen that tremors are not observed.

2.—With a high gradient tremors are almost always observed, but when the gradient is small it is seldom that tremors are visible.

3.—The stronger the wind the more likely is it that tremors should be observed.

4.—When there has been a strong wind and no tremors, such wind has very often been local or blowing inland from the Pacific Ocean. We must not overlook the fact that such winds are sometimes accompanied by tremors. Winds of short duration are seldom accompanied by tremors.

5.—When there has been little or no wind in Tokio, and yet

tremors have been observed, in most cases there has been a strong wind in other parts of Central Japan. In the case of winds working up Japan from the S.W. this has been very marked, tremors being felt in Tokio several hours before the arrival of the wind.

When neither wind nor tremors are to be observed in Tokio there is usually a general calm in Central Japan.

6.—From the observations in 1886, Trans. Seis. Soc. Vol. XI. p. 58, we see that there were 10 days out of 45 when there were tremors which could not be accounted for by winds blowing at a distance, and on p. 61 that there were 3 days out of 20 when there were winds which ought to have been accompanied by tremors, while tremors were not observed. By combining these observations we may say that about 80 per cent. of the tremors observed in Tokio may be accounted for as the result of distant or local winds.

From the observations made in 1885 it seems that 50 per cent. of the tremors certainly accompanied strong winds, while 25 per cent. of the remaining tremors *might* have been due to wind. The remaining 25 per cent. of the tremors observed may have been of subterranean origin. These tremors were of *short duration and feeble.* Out of 685 observations when it was calm in Central Japan *slight* tremors were only observed 34 times, that is in less than 5 per cent. of the number of times of observation.

7.—The earthquakes which have been recorded do not appear to be connected with earth tremors more than that each are more frequent at the same seasons.

8.—Earth tremors are as severe upon the summit of a lofty mountain as they are in the plains.

DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1886. Dec. 22	ST	—	w W o	
23	ST	—	o o w	
24	ST 7 to 10 p.	—	o W w	Low bar. North Yezo.
26	NT	—	o o o	
27	NT	—	o o o	
28	NT	—	o w w	
29	NT	—	o w o	
30	ST 5 to noon	—	o W o	Low bar. in North Yezo.
31	VST	—	W w W	Low bar. in North Yezo.
1887. Jan. 1	NT	—	o o o	
2	VST	—	o w o	Low bar. in North Yezo.
3	2 to midnight at maximum 4 p. strong	—	o W W	At 2 p.m. Tokio wind 1 but heavy wind of 4 and 5 coming up the country from W., same at 9 p.m. Bar. low in North Yezo.
4	ST	—	w W o	Bar. low in North Yezo.
5	ST morning	—	w w o	Bar. low in North Yezo.
6	ST	—	o w o	Bar. low near Tokio.
7	T	—	o W W	At 2 p.m. Tokio wind 1 but heavy wind of 4 and 5 coming up country from W., same at 4 p.m. Bar. low in Yezo.
8	8 a. to 2 p. T	—	o W w	Conditions nearly same as on the 7th.
9	ST	—	o W w	Bar. low in North Yezo. In Tokio bar. high, 770 mm.
10	ST	—	o o o	
11	1 p. maximum at midnight	—	w o w	In afternoon low bar. 758, over Tokio.
12	T	—	W W o	Low bar. N.E. of Tokio. In Tokio 764 and 768.
13	ST	—	o o o	Low bar. in Yezo. In Tokio 769.
14	9 a. to 10 p. T	—	o W W	Low bar. S. of Tokio, 765 to 756.
15	ST	—	WT4 WT4 WT3	Low bar. N. Yezo. Wind strong to S.W.
16	NT	—	W WT3 W	Low bar. N. Yezo. Wind strong to S.W.
17	NT	—	o o o	
18	NT	—	w W w	Bar. low to S.W.
19	NT	—	o o w	
20	NT	—	o o o	
21	NT	—	w w w	
22	NT	—	w o w	
23	NT	—	o o o	
24	NT	—	w w o	
25	ST	—	w WT3 WT3	Bar. low to S., Tokio 767-763.
26	NT	—	w o o	Bar. low to S. and S.W. Tokio 764-766.
27	NT	—	o o o	Bar. low to S. and N.W.

Date.	N.N.E. Component.	N.N.W. Component.	Wind.	Remarks.
1887.				
Jan. 28	NT	—	o o o	
30	ST	—	W W WT4	Bar. low to S.W. and centre passed up E. coast to N.
31	ST	—	WT3 w o	Bar. low to N.E.
Feb. 1	ST	—	W W o	Wind coming up from S.W. Bar. low to North.
2	ST	—	o o o	
3	ST	—	w w o	Tokio bar. 765-754.
4	ST	—	o W W	Tokio bar. 758-759. Wind from W. and N.W.
5	ST	—	WT4 W W	Bar. low in N. Tokio bar. 759-760.
6	NT	—	wT3 W o	Bar. low in N. Tokio bar. 761-764.
7	NT	—	o o o	Tokio bar. 766-762.
8	NT	—	o WT3 o	Bar. low in N. Tokio bar. 758-760.
9	NT	—	w o o	
10	NT	—	o WT3 o	
11	ST in morning	—	o o o	Bar. low to N. Tokio bar. 768-769.
12	NT	—	o o o	
13	NT	—	o o o	
14	NT	—	o o o	
15	ST	—	o W W	Bar. low to N. Tokio bar. 760-769.
16	NT	—	WT3 o o	
17	NT	—	w o o	
18	NT	—	o w o	
19	ST	—	o o WT3	At 2 p. strong wind to S.W.
20	ST	—	o w o	Bar. low to S. of Tokio. Tokio bar. 766-761.
21	ST	—	o w o	Bar. low to S. of Tokio. Tokio bar. 761-763.
22	ST	—	w o o	Bar. low to S. and W. of Tokio. Tokio bar. 765-767.
23	ST	—	o w o	Bar. low to S. and W. of Tokio. Tokio bar. 767-766.
24	ST	—	WT3 WT3 w	Bar. low to W. of Tokio. Tokio bar. 766-767.
Mar. 1	NT	—	o WT3 w	
2	NT	—	o WT3 WT3	
3	NT	—	o W w	
4	NT	—	o w w	
5	NT	—	o o o	
6	NT	—	w o o	
7	NT	—	WT3 w o	Bar. low to S.W.
8	ST	—	w o w	
9	T maximum at noon.	—	W W W	Bar. centre travelling from S.W. to N.E. over Tokio 738-745.
10	T	—	W W w	
12	ST	—	o W W	Bar. centre on N.W. coast. In Tokio 759-747.

DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
Mar. 13	NT	—	W W W	Tremors ought to have been recorded.
14	NT	—	o WT3 o	
15	ST	T	o W W	Bar. low in Yezo. Tokio 755-760.
16	T and irregular waves.	ST afternoon.	w w o	Bar. low in Yezo. Tokio 765-770.
17	T and irregular waves.	—	o w w	
18	T	T from 8 a. to 4 p.	W W W	Bar. low in North. Tokio 745-750.
19	ST	NT	w w w	Bar. low in Yezo. Tokio 756-763.
20	NT	NT	o o o	
21	NT	NT	o o o	Low bar. near Tokio. Tokio 763-761.
22	ST at midnight.	VST	o o o	
23	NT	NT	o o o	
24	ST and irregular waves.	NT	o WT3 o	Bar. low in Yezo.
25	Irregular waves.	NT	o W o	
26	NT	NT	o w o	
27	NT	NT	o W o	
28	T and irregular waves.	NT	W W W	Bar. low in Yezo. Tokio 750-756.
29	T and irregular waves from noon.	T to noon, not working.	W W W	Bar. low in Yezo. Tokio 757-757.
30	T and irregular waves.	NW	WT3 W W	Bar. low in Yezo. Tokio 759-761.
April 1	NT	NT	o o w	
2	ST and irregular waves.	VST	w W W	Bar. depression coming up E. coast. At 9 p. near Tokio. Tokio bar. 763-747.
3	ST	ST	w W W	At 9 p. depression travelled to N. Yezo. Tokio 744-746.
4	ST	VST until 2 p.	W W W	Depression in North. Tokio 748-759.
5	T and irregular waves.	NT	o w w	
6	NT	NT	o W w	Bar. in Tokio 764-760.
7	ST	NT	o w w	" " " 760-764.
9	T maximum 6 p.	ST noon to 6 p.	w W w	" " " 759-759.
10	NT	NT from 2 p. not working.	WT3 W w	" " " 763-765.
12	T	ST	w W W	" " " 755-753.
13	ST	NT	o w o	" " " 758-761.
22	T maximum 11 a.	ST	w w o	" " " 756-758.
23	ST	NT	o w o	" " " 759-762. Bar. depression to East.
24	NT	NT	o w o	Bar. in Tokio 764-768.
25	NT	NT	o WT3 w	" " " 771-770.
26	NT	NT	o w o	" " " 770-769.
27	NT	NW	o w o	" " " 768-765.
29	T maximum 1 p.	NT	o W w	" " " 766-765. Bar. low to S.W.

Date.	N.N.E. Component.	N.N.W. Component.	Wind.	Remarks.
1887.				
April 30	T and irregular waves.	ST	W W W	Bar. in Tokio 761-750. Bar. low to W. and N.W. of Tokio.
May				
1	T at 5 a. and irregular waves.	T 4 a.m. strong afterwards slight.	W w w	Bar. in Tokio 753-761.
2	T and irregular waves.	ST at noon.	w o o	,, ,, ,, 764-762.
4	T and irregular waves.	NT	o W w	,, ,, ,, 766-769.
5	T and irregular waves.	NT	o o W	,, ,, ,, 771-772.
6	ST and irregular waves.	NT	o w o	,, ,, ,, 771-767.
8	ST	NT	o W o	,, ,, ,, 758-759.
10	ST	NT	o w o	,, ,, ,, 759-759.
14	T in morning	T 10-12 a.	W W w	,, ,, ,, 759-760. Bar. centre passing up E. coast.
16	ST	ST	o W W	Bar. in Tokio 759-756. Low bar. in Yezo.
17	NT	NT	w WT3 w	Bar. in Tokio 761-763.
18	NT	NT	WT3 o o	,, ,, ,, 763-765.
19	NT	NT	o WT3 WT3	,, ,, ,, 760-765.
21	NT	NT	o w o	,, ,, ,, 758-758.
22	NT	—	o WT3 w	,, ,, ,, 758-755.
23	ST	ST	o W w	,, ,, ,, 755-756.
24	NT	NT	o o WT3	,, ,, ,, 757-760.
27	ST and irregular waves.	—	o WT3 o	,, ,, ,, 765-764.
28	NT	NT	o w w	,, ,, ,, 763-759.
29	NT	NT	w w o	,, ,, ,, 757-754.
June				
3	NT	NT	o w o	
6	Irregular waves.	NW	o w w	Low bar. over Tokio. Tokio 755-754.
7	NT	NT	o w o	Low bar. near Tokio. Tokio 756-758.
8	NT	T from 11 p.	o w WT3	
9	T from 1 a.	Afternoon NW	w o o	
20	T	ST	o w W	Low bar. near Tokio. Tokio 761-747.
21	ST	ST	o WT3 o	Tokio 748-755.
22	ST	ST	o w o	Bar. low to W. of Kiushiu. Tokio 756-758.
23	ST	NW	o W W	Low bar. near Tokio.
24	T	ST	o w W	Low bar. near Tokio. Tokio 750-758.
25	ST	NT	o WT3 o	Tokio 757-754.
26	NT	NW	o o w	
27	ST	ST	w w WT3	
July				
22	Irregular waves.	NT	o W o	Wind of force 3 only at 2 places near each other.
24	NT	NT	w W o	Wind of force 3 only at 2 places near each other.
25	Irregular waves.	NT	o W WT3	Wind of force 3 only at places near each other.

Date.	N.N.E. Component.	N.N.W. Component.	Wind.	Remarks.
1887.				
July 26	Irregular waves.	NT	o WT3 o	
27	Irregular waves.	NT	o o o	
28	Irregular waves.	NW	o W o	Wind of force 5 only at 5 places near each other.
Aug. 1	Irregular waves.	NW	o w o	
2	NT	NW	o w w	
3	Irregular waves.	NT	o w o	
4	NT	NT	o w w	
19	Irregular waves.	NW	o w o	
22	Irregular waves.	NW	o o o	
29	ST	ST	w W w	
30	NT	NT	w w o	
31	NT	NT	o WT3 o	Bar. low to W. and N. Tokio 763-763.
Sept. 1	NT	NT	o W o	
2	NT	VST	o W o	
4	NT	NT	w w o	
5	NT	NW	o w o	
7	Irregular waves.	NT	o WT3 o	
8	NT	NT	o WT3 o	
9	NT	NT	o w o	
13	T and irregular waves.	ST	o w W	
14	T	ST	W W W	Bar. low in N. Yezo.
15	ST	ST	W w w	
16	ST irregular waves.	NT	w W o	
18	NT	NT	o o w	
19	NT	NT	o w o	
20	NT	NT	o W W	
21	T irregular waves.	NT	o o w	
22	ST	ST morning afternoon NW	o o o	
23	T	T	W W o	
24	T to 10 a. after NT	NT	W w o	
25	NT	NT	o w w	
26	T	NT	o w o	
27	ST	ST	o W w	
28	ST	NT	w w o	
29	ST	NT	o o W	
Oct. 7	VST	VST	W W w	Bar. low in N. Yezo.
24	T	VST	o W w	

Date.	N.N.E. Component.	N.N.W. Component.	Wind.	Remarks.
1887.				
Oct.				
25	T	NT	o w o	
26	T	NT	w w w	
27	T	NT	w w o	
28	T	NT	o o o	
29	ST	NT	o o o	
Nov.				
6	VST	T in morning	o o o	
7	ST	NT	o o o	
8	ST	NT	o WT3 o	
11	NT	NT	w w o	Bar. low near Tokio.
13	T	ST	o o o	
14	NT	NW	o o o	
18	NT	NW	W w o	
19	NT	NW	o o o	
20	NT	NT	o o o	
21	NT	NT	o o o	
24	ST	NT	o w o	Bar. high over Tokio.
25	T	NT	o o WT3	
26	NT	. NT	o w w	
27	ST	NT	o o o	
28	NT irregular waves.	NT	o o o	
29	T	NT	o o W	
30	T	NT	W W w	Bar. low over N. Yezo.
Dec.				
1	T	ST	o w o	
2	T	ST	o W w	
3	ST irregular waves.	NT	WT3 W o	
4	ST irregular waves.	NT	o o o	
5	ST irregular waves.	NT	w W w	
6	ST irregular waves.	NT	o o o	
7	ST irregular waves.	NT	o o o	
8	ST irregular waves.	ST	o w w	
9	NT	NT	o w o	
10	ST	NT	o o o	
11	ST	NT	W W o	
12	VST	NT	o W w	
13	VST	NT	w o o	
14	NT	NT	o W W	
15	NT	NW	W W w	
16	T	NT	o w o	
17	T	ST	o o w T3	
18	T	NT	o o o	
19	ST	NT	WT3 w w	

Date.	N.N.E. Component.	N.N.W. Component.	Wind.	Remarks.
1887.				
Dec.				
20	ST irregular waves.	NT	w o o	
21	ST	NT	o o o	
22	ST	NT	o o w	
23	VST	NT	w w o	
24	VST	NT	o w W	
25	NT	NT	o W W	
26	VST	NT	w w o	
1888.				
Jan.				
3	NT	NT	w o o	
10	NT	NT	o o o	
11	NT	NT	o w o	
12	VST	NT	o W o	
13	VST	NT	o o o	
14	NT	NT	o W w	
15	NT	NT	o WT3 o	
16	VST	NT	o o o	
17	VST	NT	o o w	
18	NT	NT	o o o	
19	NT	NT	w w o	
20	NT	NT	o o w	
22	NT	NT	o o o	
27	NT	NW	o W o	
31	VST	NT	o o o	
Feb.				
1	NT	NT	w W w	
2	NT	NT	w WT3 o	
3	NT	NT	o o o	
6	NT	NT	o o o	
8	NT	ST	o o w	
9	NT	NT	w W o	
14	VST	NT	w w o	
15	NT	NT	o w w	
16	NT	NT	o o o	
17	NT	VST	o o o	
18	VST	VST	o WT3 o	
20	NT	VST	w W W	
21	NT	VST	w w o	
22	VST	VST	o o w	
23	NT	VST	o WT3 o	
24	NT	VST	o W w	
25	NT	NT	o w o	
26	NT	NT	o w w	
27	NT	NT	w W w	
29	NT	NW	o w o	

RESULT OF ANALYSIS.

From a general inspection of the weather maps it is quite clear that, when little or no wind is indicated or when the isobars are few, no tremors are recorded, while on the contrary when the wind is strong at many stations in Central Japan and when the isobars occur in close proximity tremors are almost always recorded. On the Japanese maps the isobars are drawn with intervals of 5 mm. of pressure. On the Italian maps where the intervals are only 1 mm., the relationship between tremors and the frequency of isobars, which when they are numerous indicate a steep gradient, is even more marked than it appears to be in Japan. On the Italian maps which are published under the direction of Professor M. S. de Rossi, the state of the wind is not indicated, but it may be inferred that when the gradients over the Italian Peninsula are steep, wind is blowing somewhere in the Peninsular, and therefore in Italy, as in Japan, tremors are accompanied by wind although the wind may not be blowing at some particular place where tremors are observed. Certainly tremors often occur with a low barometer, but the greater frequency of tremors apparently happens when the gradient is steep no matter whether the barometer is high or whether it is low, and cases may therefore be observed of low barometers unaccompanied by tremors, as for example on May 29th, 1887. Observations like these have inclined me to the opinion that tremors are more closely connected with wind than with barometric pressure.

An examination of the preceding tables shows:—

1. That there are 80 cases of well pronounced tremors having occurred with strong winds blowing in Central Japan. In several instances tremors were observed in Tokio some hours ahead of the wind which was blowing heavily to the S.W. and travelling up the country towards Tokio. (See January 3rd and 7th, 1887, also previous paper).

2. There have been 40 cases of strong wind and no tremors.

In 34 of these cases the wind has been local or of short duration, that is to say wind was only blowing in Tokio, or it was only observed at one of the tri-daily observations. In the remaining 6 cases (January 16th, Febrary 6th, March 13th, September 20th, December 14th and 25th) if tremors are the result of wind they ought to have been observed.

3. With no wind and no tremors there are 79 cases.

4. With no wind and *small* tremors there are 63 cases. In 39 of these cases the record on one band of paper showed no tremors and therefore these 29 cases might have been classified in the preceding group. On the other band tremors were barely visible. In 8 out of the remaining 26 cases (January 11th, 13th, February 2nd, 3rd, March 16th, 17th, April 7th and 13th) the tremors observed were immediately in advance of a heavy wind, or were tremors continuing after a large wind had passed, at which time tremors had been well pronounced. There are therefore only (26—8) 16 cases when tremors can be said to have occurred when there was no wind, and these cases occur when only one band of paper for receiving records was working.

The above results may be tabulated as follows :

1.—Strong wind and well pronounced tremors.........	80
2.—Strong wind and no tremors 40 cases, which may be subdivided into :—	
Cases were tremors ought to have occurred	6
Cases where the wind was local or of short duration and it is therefore doubtful whether tremors should have been recorded..........................	34
3.—With no wind and tremors.............................	79
4.—With no wind and *slight* tremors 63 cases, which may be subdivided into :—	
Cases where tremors were so small that they were only recorded on one band of paper (39 + a possible 16)	55
Cases which may have been due to wind	8
Total..	262

The conclusion is that out of 86 cases of wind there are only 6 cases when tremors were not observed, while when there was

no wind generally there were no tremors, or at most tremors so slight that they were barely recorded. A result which agrees with that arrived at previously.

For three months an automatic spark record was kept of tremors which might be due to vertical motion, but as these only occurred when tremors were recorded by the machine already described and were extremely small, the observations were discontinued. The instrument employed was a horizontal lever spring seismograph with an index having a multiplication of about 100.

HOW WERE THE CONE-SHAPED HOLES ON BANDAISAN FORMED?

By E. Odlum.

[Read December 4th, 1888.]

Before saying anything about the different theories advanced to explain this question, it is right and proper to say that Professor Seikya and Mr. F. Kikuchi, Assistant Professor of Geology in the Imperial University, have ably pioneered the way for the true explanation. In fact they have done more. They have met several or all of the objections raised against what must finally be accepted as the only scientific explanation of many, if not of the large majority of the numerous cone-shaped holes to be found all the way from the broken crater edge, and the adjoining peaks, down to the valley below. The testimony of these gentlemen is of the greatest value, as they have made an extensive and scientific exploration of the entire region affected by the eruption. As their report was given in lecture form by Professor Seikya, there is no need of making any general observations concerning the outburst. It is the aim of this paper to deal only with the cone-shaped holes.

That there are vast numbers of such holes, probably hundreds of thousands, all admit. That most of them were formed during the eruption all are agreed. That they are found scattered irregularly in all directions from the peaks to the valleys below is known by those who have examined them. That many theories have been advanced to account for them is now a matter of history.

THE DIFFERENT THEORIES.

A. Solfataras—*i.e.* vents from which issue sulphureous gases.

B. Steam and other gaseous vents.

C. Seismic action operating on bodies of matter concealed in the mountain slopes.

D. Falling stones.

E. Human agency.

F. The uprooting of vast numbers of trees by the combined force of the earthquake shock and hurricane which prevailed at the time of the eruption.

Some of these theories may be dropped at once, as they are not accepted by any one who visited the scene of the outburst.

A. "Solfataras" as a theory is dropped, and never was held by more than one or two.

B and *C* may be passed over for the present as the former has no following now, and the latter is only a theory, which has not yet produced *one fact* to give it any lasting claim as a general explanation.

We shall now consider *F* for a moment.

Those who have travelled over the mountain slope know well that almost all the large trees have been blown out by the roots. This is true concerning the trees on at least one half, if not two-thirds of the mountain, from the peak downward. Large quantities of clay, sand and gravel adhered to the roots and thus many large holes were formed. In many cases the great force sent the trees a little distance from the place on which they stood, and in a few instances turned them completely over; but the large majority are lying with their roots close to the holes made by their falling, with their tops pointing down the mountain. This is enough to show that many holes were formed by trees blown out by the roots.

Let us now look at *E* for a moment. It certainly sounds strange to say that large numbers of the cone shaped holes

were formed by *human agency*. Nevertheless it is true, and easily proved.

While examining the holes carefully, with the object in view of seeing what were the facts, the men whom I had engaged to dig, concluded that there was no use of digging any further in one of the holes in which I was interested. In fact they were determined to stop, because they *knew* there was no stone in that particular hole.

To convince me, they pulled out some small *pine roots* and set them afire, and informed me that the people in the villages, dug out many such *pine roots* for the purpose of getting material for fire and for *light*.

This seemed very strange, but was worth considering. Towards evening a labourer came down from the heights above witn a large load of *pine roots* on his back. He gave the same information as the diggers. On returning to the village of Inawashiro the same facts were again substantiated.

Professor Seikya looked into the matter carefully, and in reply to a letter on the subject, sent by him to a friend in the Bandaisan region, received the following answer, which he has kindly translated for my use:—

"It is very natural for you to ask that question." (The writer of the letter was interrogated as to the use of the Pine Roots.) "Pine Roots are used for *lighting* purposes. They contain an abundance of resin—so much so that some of them are semi-transparent-light. Some of them give better light than oil or candles. In winter nights they also serve for heating rooms, and are mostly used among the peasantry. Call them *farmer's lamps* if you like. The price for one stump is below 10 *sen*. Sometimes owners of the forests allow people to dig them gratis, I suppose for their own convenience. One large root often requires two or three horses to carry it, but lasts six months for one household. Being so cheap, convenient and near at hand no wonder almost every farmer goes to the mountains for them—the reason why you find so many holes on the slopes of Bandai and Akahagi."

I wrote to Mr. Kinichiro Hasegawa, the chief of police at Inawashiro, a gentleman who did all he could to answer my questions carefully, and comprehensively; and he sent the following reply:—

"After careful examination I gained this information. Digging up pine roots is done not only by one or two villages but by nearly all the villages around the mountains. They use them for light when they are working at night. They are used chiefly by the poor."

From these two letters and the other facts already mentioned, we readily see that a large number of holes was formed in this manner. These holes are conical; and, as a large amount of earth is dug out to clear away the roots, there is also a rim of earth around them, much the same as around these formed by the falling stones. It is impossible to tell these two kinds of holes apart, without actual digging. When the ashes, or volcanic dust fell over the slopes of the mountain, it covered the *old pine stump holes* and also the *new holes made by falling stones* in such a manner as to make them look alike.

We now come to the chief topic, to the consideration of *D.* It must be examined into most carefully, as this particular phase of the question has been the chief "bone of contention."

Before a proper answer can be given to the question "Did falling stones make a large number of the holes on the slopes of Bandai-san?" we must decide that stones were projected into the air at the time of the eruption. If they fell they were projected, and vice versa.

1ST.—Did stones fall?

A. Many eye witnesses have testified to the fact that they fell in immense numbers. The newspaper correspondents, sightseers, amateur and matured scientists, have given overwhelming testimony proving that stones, countless in number, both large and small, fell with terrific violence all over the slopes of the mountains.

B. Many persons were wounded and two, *at least*, were killed by falling stones.

C. The ruins of villages, and broken trees of all sizes show that they were bombarded by stones both small and large. In fact all admit that *Yes* is the true answer to the question *did stones fall?*

2ND.—Where are these stones?

A. They must be *above* or *beneath* the surface of the earth. They fell in all directions, mostly to south-east, and in some cases to the distance of *five miles* from the crater. Most careful search reveals the fact that they are nowhere to be found, and therefore they are not above the surface.

B. If they are below the surface they must have penetrated, by the great force gained while falling thousands of feet through the air, *into the earth* several feet, leaving large holes to mark their present resting places.

C. It is inconceivable to suppose they buried themselves in the earth without making holes.

D. Are there holes? Yes, *tens* or *hundreds of thousands.*

E. In many of these holes are found fresh, angular, ash covered stones of different sizes.

F. Under all the stones dug out there were found grass, leaves, weeds, branches, and other kinds of vegetable matter, which had been carried down by their lower surface. These different plants were mostly bruised until little remained but the coarse tough woody fibre which has the appearance of having been passed between heavy iron rollers.

G. In one hole the large stone had struck on a boulder of the mountain mass, and ground or crushed the corner into powder. The stone had almost come to rest before it came in contact with the old imbedded rock or boulder, so that the corner of each, at the place of impingement, was pulverized to the extent of not more than four or five inches square, but it was quite fresh.

3RD.—Running down the mountain slopes from the tops to the valleys are many gorges, some of which are very deep, and at places along their bottom may be found comparatively level spots.

Such places were visited and many holes found in them. But the holes are just as numerous on the slopes of these gorges, and on the ridges between two adjoining gorges as iu

their valleys. If seismic action operating on water were the cause of the holes, we would expect the holes to be in the gorges and along the water-ways, *but not all over the high and dry ridges hundreds of feet above*, as is undoubtedly the case.

4TH.—The solid, bare, native, mountain rock has on its upper surface marks and large scars which could have been made only by falling stones. In Fig. I., *A* and *B* represent two very important phases of this question. In *A*, *CC* is the native rock, *X* represents a coarse irregular scar made by the falling body; *Y* the dark spot in the centre is intended to show *what would have been the case* if the huge fracture were made by steam, gas, or water action from below. Undoubtedly there would be a hole corresponding to *Y*. *Such a hole does not exist.* But the scar is represented by the centre *t* in *B*.

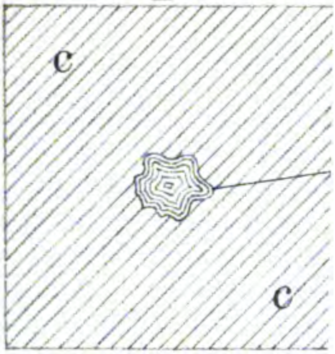
5TH.—As said before, the trees show most conclusively that stones were hurled with great violence through the air. Fig. II. is a sketch of a tree about half a mile from the crater. In the shattered trunk, the stone is imprisoned in the splinters, as shown in the diagram at *S*.

6TH.—Fig. III. represents one of the holes found on a level spot in one of the gorges before mentioned. Its diameter is 31 feet, and depth about 10 feet. The crater is about *five miles* distant in the direction of *C*. The rim of earth is deeper and larger on the side marked *B*. This is most natural. If the stone fell perpendicularly, the rim of earth would be the same general size all around the the hole, but as the stones fell in a slanting direction, and *away from the crater*, the rim of earth is larger at *B*, *i.e.* on the side distant from the crater.

7TH.—On digging into these holes and examining the position of the stones, I found that they were not in the centre, but to one side, and always on the side *distant from the crater*.

In fig. IV. *C* is a large hole about 10 ft. in diameter; *AA* is a perpendicular erected at the centre of the hole; *BB* is a

B



C

A

perpendicular from the centre of the stone. The crater is fully four miles distant in the direction of *Y*. The distance from *AA* to *BB* is about 10 or 12 inches. This distance is varied according to the shape of the surface and the material on which the projectile fell.

8TH.—On many parts of the mountain the small trees and shrubbery are very dense. Among this thick growth some important facts were observed. In fig. IV. *D* is a large hole about 15 ft. in diameter. *Rt.* is the mountain slope. The crater is off in the direction of *X* between 3 and 5 miles. As the stone came crashing to the earth, it cut its way through the bushes, tall grass, and weeds, bending them in *the direction s c*; but as the earth was forced out on the lower side of the hole, the shrubs and small plants were bent *away from the centre toward the base* of the mountain.

9TH.—The weeds, leaves, branches, etc., found under these stones, correspond to those growing around the hole.

10TH.—Where the stones fell on the steep slopes of the mountain so steep as to make the angle *CDE* 45° or more, fig. V. *CD* being the inclined surface where the hole was made, the earth rim is found *on the lower side only* as at *n*; and the distance from the upper side of the break to the lower centre of the hole is much greater than that from the centre to the surface on the lower side, *in some cases twice as great.*

NOTE.—The mountain slopes are for the most part soft mud, sand and deteriorated volcanic scoriæ. This is true of nearly all the mountains of Northern Japan.

11TH.—The rim of earth thrown out is for the most part fairly regular in its shape, and confined within a distance of a few feet from the edge of the hole. Very seldom is it more than 10 feet from the edge of the hole to the outer edge of the rim. If the holes were made by steam, gas, or water action from below they would have around them very irregular rims of dirt, which would be scattered hundreds of feet from the centre. This is *not* the case.

12TH.—On reaching these stones, careful examination was made beneath them. We turned them over, and continued digging to see if the ground below was solid, or loose and crumbling. We found it *solid*; just like the well compacted earth generally found by digging to a distance of 6 to 12 feet. Had there been a "blow up" from below there would be some signs of such action. No such signs were found. The earth would have been loose, *but it was solid.*

13TH.—That stones are not found in all the holes may be readily explained by the fact, before mentioned, that many holes were made by people digging out pine-roots.

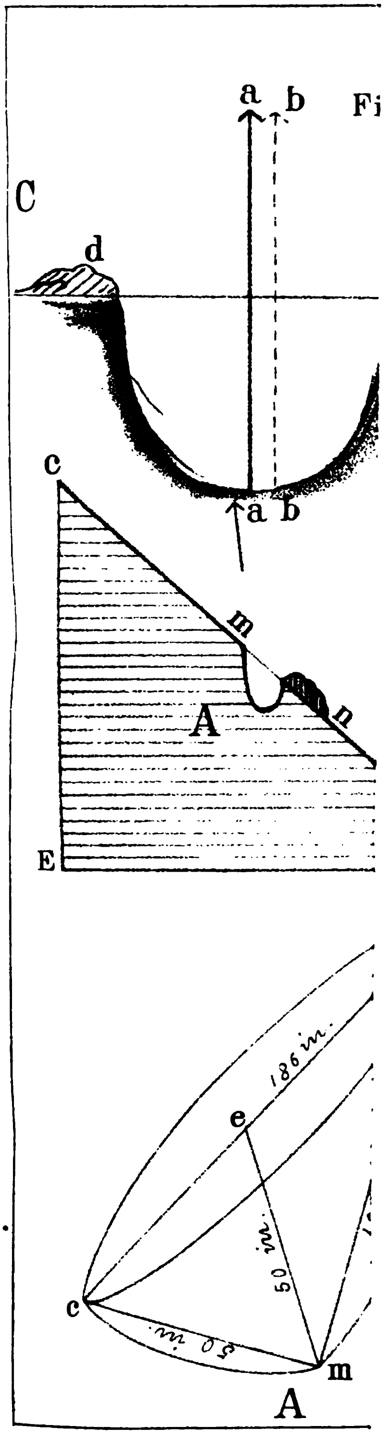
14TH.—Many of the holes were measured. They vary from a few feet in diameter to over thirty feet, and from 2 to 10 feet in depth.

The following table gives the measurements of a few of those most carefully examined.

1.—	7 feet diameter,	3 feet deep.
2.—	5 feet diameter,	1¾ feet deep.
3.—	15 feet diameter,	5 feet deep.
4.—	10 feet diameter,	3½ feet deep.
5.—	31 feet diameter,	10 feet deep.
6.—	10 feet diameter,	2 feet deep.
7.—	20 feet diameter,	6 feet deep.
8.—	20 feet diameter,	5 feet deep.
9.—	10 feet diameter,	5 feet deep.

15TH.—The ratios between the diameters and depths of the holes low down the mountain sides are different from the ratios between the diameters and depths of the holes near the summit. Above, *i.e.* near the peak, the diameter is greater than the depth in comparison with the same functions below.

This is natural. The stones which fell near the summit did not fall so far, and therefore their final velocity was less; while those reaching the ground far down the mountain had much farther to fall, in some cases between 3,000 and 4,000 feet. Hence the final velocity would be much greater and they would penetrate to a greater depth in proportion to the diameter.


a
b
Fi
C
d
a
b
c
m
n
A
E
186 in.
e
50 in.
c
50 in.
m
A

16TH.—Some think the holes are too large to be made by the stones found in them. But when we consider the height from which they fell, and their momentum, we can readily believe they made the holes in which they are found.

One excavated stone had the following measurements, as nearly as could be ascertained.

It measured 27 × 35 × 40 inches.
This gives 37,800 cubic inches.

Taking the specific gravity as 2.5, which is a little above the fact, as shown by the results arrived at by Professors Sekiya and Kikuchi, the total weight would be 3,975 lbs. Suppose the stone fell 7,744 feet, which is a very moderate height, the final velocity would be 704 feet per second.

This gives a momentum of 2,798,400 foot pounds and a working energy of 30,782,400 foot pounds.

This force, or capability for performing actual work, is simply inconceivable; even after due allowance is made for atmospheric resistance, which would be considerable.

17TH.—The average tendency of steam, gas, or water action in forming holes on the slopes of the mountains, would be to emerge at right angles to the surface, as indicated by *m n*, in fig. *V. B*, or *a h*, *but not K R, as is really the case in all the holes so situated.*

Again, if the holes were formed from below there would be considerable ejecta all around, *on the upper side*, as well as the lower, which is not the fact, as inspection shows in fig. V. *A*. There is no rim of mud at *m*, on the upper side, but much at *n*, below.

18TH.—In fig. VI., *A* is a hole from which a large boulder was taken; *c d* is 186 inches, *c m* 50, *d m* 100, *e m* 50. In *B*, *c d* is 13 feet, *c m* 8, *d m* 11 and *e m* 7½ to the top of the stone, *s*. X represents the direction of the crater from *A* and *B*.

NOTE I.—While these holes are generally spoken of as cone-shaped, quite a number are not of such a form, but vary considerably owing to many cir-

cumstances, such as position of surface and the heterogeneity of the material on and under the surface.

NOTE II.—Although the term *ashes* is used to indicate the pale blue *volcanic dust*, serious doubts are held concerning their true composition. I think they may be more correctly considered as fine dust resulting from the pulverizing of the soft stones and clay of which the mountain is mostly formed. Stone dust, or volcanic dust would, perhaps, be a better term.

19TH.—Besides the objections already made to the theory that the holes were formed by seismic force operating upon water and forcing it to perform the wonderful feat of blowing out tens of thousands of holes all over the mountains from their peaks to the valleys, not only in the lower parts, but along the dry tops of the ridges, another objection may be raised. It is as follows:—

The whole mountain looks as if it had a heavy attack of small-pox. Now, to suppose each hole, or every second, or third hole, was formed by water action is to suppose such a quantity of water in all parts of the mountain as would have turned the entire mass into muddy slush, which would have run down into all the adjoining valleys long before the eruption could have taken place. Such a mountain could not stand half an hour.

20TH.—The innumerable holes of all sizes on the inner slopes of the crater and on the peaks are most difficult to explain. Doubtless many of them were caused by falling stones, and perhaps a number of them by steam or gaseous action as indicated in the beginning of this paper.

In the marsh known by the name of Numanotaira, the explanation so ably advocated by Mr. J. Milne, Professor of Mining in the Imperial University, may be true for some of the holes. Here of course is a large quantity of water which must have under its lower surface many fissures filled with water. In such a spot there is reason for the hypothesis of seismic action. But this marsh is not the one thousandth of the area dotted with holes, and is close to the crater, comparatively speaking.

21ST.—Why are the holes more numerous towards the north east side of the mountain?

A. The wind, which was blowing E.S.E at the time, would have a tendency to carry all the material projected into the air in the same direction. In 30 to 50 seconds this wind would certainly move the stones somewhat out of their course, and especially so, if the wind at a great elevation was very strong, as it was in all probability. This we may infer from the fact that large quantities of the volcanic dust were carried 60 miles distant with the wind.

B. Perhaps the fierce hurricane rushing down the sides of the mountain would aid in driving much of the ejecta, including the stones, towards the north-east. Looking over the different parts of the mountain, and excluding the north, in the direction of the great outburst, one is led to believe the hurricane force was stronger on the N.E. side than in any other direction.

C. But the chief cause may be understood by looking at Fig. VII.

There are four peaks:—*A*. Kushigamine, *B*. Akahagi, *C*. Ôbandai, and *X*. Kobandai, the peak that erupted northward towards *D*.

The dark, cone-shaped mass is intended to represent the peak in the act of lifting. The enormous steam or gas pressure that lifted the cone, having an altitude of between two and three thousand feet, with a volume of 158,700,000 cubic yards as shown by Prof. Sekiya, and hurled it many miles over a large area, found an immense vent at the north side. From this vent issued vast masses of stone ash, mud, and hundreds of thousands of stones. The high peak *C*, Ôbandai, in close proximity, and the other high summit *A*, Kushigamine, on the east, would to a very large extent turn the force of the northward explosion through the low and large opening between them, *i.e.* between *A* and *C*. This would cause the mass of projected matter to pass north-east over the lower peak *B*, Akahagi.

This, is perhaps, a reasonable explanation for the appearance of the great quantity of mud and boulders which came north-east to Mine, and does away with the necessity—according to some—of supposing there are two distinct craters.

NOTE.—True there are many stones and boulders visible in and on the mud areas; but they came down the mountain gorge or valley mixed up with the mud, and did not fall from the crater on the mud after it had come to rest.

In presenting the above facts, I have felt encouraged because the gentlemen who have the management of the Seismological Society of Japan in hand, men whose labours are well known among scientists of other lands, who stand in the front ranks in their several departments of research, and whose only object is to patiently and faithfully glean the gems of truth from the broad and rugged fields of nature, are the gentlemen who have given me this opportunity to add my little to the much already harvested, and in whose hands, one, in his inability to do justice to the work undertaken, feels safe, knowing that not only fairness but even leniency will be cordially manifested.

DISCUSSION.

Professor Milne first remarked that he had already expressed his views about the conical holes at Bandai-san but now that the matter was receiving special attention he felt that he must reiterate and express more definitely his former arguments. Continuing, Professor Milne said:—Thus far I have been in a minority of one. Professor Sekiya and his colleague Professor Kikuchi after elaborate investigations which even extended to excavating and boring in some of the holes, have arrived at the conclusion that they were formed by falling stones. Mr. Odlum who has made a special study of the pits arrives at similar conclusions, and other gentlemen who have seen Bandai-san are of like opinion. Herr Von Kreitner holds the belief that the holes were produced by steam explosions from below, and in support of his views has told us that when he and his companions were approaching one of these holes they invariably noticed a sulphurous smell, as if emanating


MARU MOR

from a solfatara. My views as to the origin of the pits is an old one, and so far as I know is one which has been considered sufficient to explain the origin of the water, mud, sand, or gas eruption at conical holes and fissures which are found over wide areas after the occurrence of every large earthquake. Such holes, which do not appear to differ in any way from the Bandai-san holes, were formed at the time of the Charlestown earthquake and the Cachar earthquake (photographs exhibited). Similar pits are described and illustrated by Lyell in his Principles of Geology, vol. II. p. 127. They were specially reported upon by a deputation of Academicians, from the Royal Academy of Naples, who examined into and wrote upon the effects of the great Calabrian earthquake of 1783. These gentlemen also dug into the holes, but we do not hear of their having found any boulders. The explanation of the pit formation which I have given is somewhat similar to that suggested by Sir William Hamilton, but more accurately expressed by Mallet. In a small book on earthquakes published in the International Series I have expressed these views as follows :— In the case of a horizontal shock passing through a bed of ooze or water bearing strata, the elastic wave will tend to pack up the water during the forward motion to such an extent that it will flow or spout up through any aperture communicating with the surface. By the repetition of these movements causing ejections, mud or sand cones like those produced by a volcanic eruption may be formed, and by a similar action water may be shot violently up out of wells as was the case in Jamaica in 1692. If an emergent wave acts through a water bearing bed upon a superincumbent layer of impervious material this upper layer is, during the upward motion by its inertia, suddenly pressed down upon the latter. This pressure is equal to that which would raise the upper layer to a height equal to the amplitude of the motion of an earth particle and with a velocity at least equal to the mean velocity of the earth particle resolved in the vertical direction. For a moment the water bearing

strata receive an enormous squeeze, and the water or mud starts up through any crevice which may be formed leading to the surface. We therefore have three theories to discuss, and I will take them *seriatim*.

1ST.—The Volcano or Solfatara Theory.—Although Herr Von Kreitner and his friends detected a sulphurous smell at the holes, may not this have been due to the decomposition of organic matter? Although such occurences are not uncommon, I did not smell anything noticeable nor did any of my numerous acquantances who have explored Bandai-san. Therefore, I conclude that the observations of Herr Von Kreitner were exceptional and not general. As a sulphurous smell was therefore exceptional, and as all the water in the holes was cold, and as there was no steam, I am strongly of opinion that the holes were not of volcanic origin. Further, were they of volcanic origin I fail to see why they should be spread over so large an area and be practically of uniform size. Some I should have expected to have been of considerable size and others small. For a similar volcanic effort to have been made at practically similar depths, at thousands of points beneath an extended area, is not only improbable but outside the history of vulcanology.

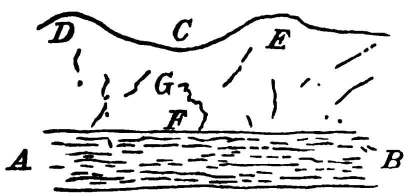
2ND.—The Falling Stone Theory.—The only experiment, of which I am aware, which supports the theory that the Bandai-san holes were formed by falling stones is that of throwing a bullet into dry sand, when the sand will splash outwards and a conical hole may be formed. The like effect, however, is not produced when a bullet is thrown into ordinary earth or clay, nor is it produced when fired through a piece of wood. In the latter case the effect is reversed and the apex of the cone is on the side where the bullet entered. A stronger objection to the theory is that the holes are tolerably uniform. When Bandai-san exploded, stones of all sizes were shot to different heights and therefore very different effects might have been

produced. Some boulders should be resting on the surface, some buried a few inches, some a foot, some two feet, and so on. The facts, however, are that it is only in a few holes that stones have been discovered just as they might have been discovered by digging anywhere in the side of a mountain; and further, they all, or nearly all seem to have had just sufficient velocity to penetrate the upper crust and then disappear in a softer layer beneath. Even supposing that the stones were shot to a height of 10,000 feet, which is double the height we can reasonably suppose them to have gone, as judged from pictures of the eruption, the velocity with which they struck the ground can not have been much over 700 feet per second. It does not seem likely that an ill shaped rock striking the ground with this velocity, which is only quarter that of a ball from a modern gun could have excavated a conical hole in moist earth 10 or 15 feet in diameter and then have buried itself in the hole it formed. The fact that perfect branches of bamboo have been found beneath one or two boulders is surely an argument that the hole was *not* formed by the falling of the boulders, which rather than carrying down with it leaves which are as perfect as if prepared for an herbarium, ought on the contrary to have crushed and broken them. Then again, amongst the thousands of volcanic eruptions, when materials have been thrown to a height of 20,000 feet, where have we an account of the falling stones producing pits? The boulders from the great eruption of Asama-yama still lie round its base, but they do not appear to have made pits. We read of huge boulders having been thrown a distance of 9 miles, but we do not read of pits having been produced by the boulders. Neither in the three treaties on volcanoes—one by Scrope, one by Daubeny, and the other by Judd, nor in many other works do I ever remember reading that pits have been produced by falling boulders. If pits have been produced at the time of a volcanic disturbance I think we shall find that such a disturbance was accompanied by an earthquake, and if the pits at

Bandai-san were formed by falling rocks it is a new and important observation in vulcanology. In the case of a meteorite we have a body passing through the atmosphere with a velocity sufficient to render itself red-hot, yet even in the case of heavy bodies such as these I do not think we read of conical holes being excavated. My own conclusion therefore is that the majority of the holes were not formed by falling stones. A few in the soft mud of the crater may have been formed in that manner, but it is more likely that the few holes in such position were made by the explosive action of steam.

3RD.—The Water Pressure Theory.—I am led to believe in this theory partly because there are so many objections to the other theories and partly because it is supported by many facts. At the time of the Bandai-san eruption there was a severe earthquake, and it is an extremely common event to have holes like those at Bandai-san formed at the time of large earthquakes. Why therefore should we seek for any other cause, when we remember that nearly all volcanoes have ejected large rocks, but it is seldom if ever that these have been known to excavate crater-like pits? It seems very improbable that the pits at Bandai-san were formed in this manner. If they were formed in this manner pits in all stages of formation should exist, the large ones being relatively few in number and each pit should contain its boulder, which in the majority of cases ought to show freshly fractured surfaces, and beneath no boulders ought we to discover branches and plants, so perfectly preserved and uncrushed as those which have been exhibited. The earthquake effort, which may be illustrated experimentally by coating a surface of water contained in a shallow vessel with alternate and irregular layers of paraffin and sand, and then tapping the surface or sides of the same, would round the immediate vicinity of Bandai-san be felt with approximately equal intensity. The effect of this upon water bearing strata at moderate depths, in bursting through the crust, we should anticipate would be tolerably uniform, and in the majority of

cases result in the formation of conical holes, rather than fissures.



Thus a disturbance passing along the water bearing strata *A B*, would tend to burst through the surface at *C*, rather than at *D* and *E* where the resistance to rupture is comparatively great. Further, the ruptures would, for the following reasons, generally take place at some particular point or points along the depression *C*, which runs at right angles to *D C E* rather than from a fissure. (1) Assuming *A B* to be of a stream-like form running at right angles to the depression *C*, in this case it would only be where *A B* passed beneath *C* that fracture would take place. (2) Assuming *A B* to be of a stream-like form but running beneath and parallel to the length of the depression *C*, or even let A B be of sheet-like form, in this case, because in the earth beneath *C* there are fissures, cracks, or lines of weakness as *F G*, which when traced along their length vary in their dimensions, at some places rising to the surface more than they do at others, there are therefore points of comparative weakness, and at such places we might expect the superficial soil to be burst through rather than at others. In some instances however, especially with very severe shocks fissures may be formed. The holes which I inspected followed an irregular line along the length of a valley on the west side of O Bandai, along a line of drainage. The boulders which have been found in such holes, so far as I am aware, are in no way different and not more numerous than I should imagine them to be in the soil lying upon any portion of the mountain side. The shape of the holes is such as would result from an explosive effort

in soil, branches of shrubs and the grass forming a fringe round the edge of such holes being blown outwards. After an explosion, much of the material, not having been projected to any height, probably in no case more than 20 feet, would fall back to the cavity from which it had been ejected, while other materials might roll down its sides. In this way I should account for boulders, grass, leaves, and the like being found in the holes—in some cases the boulders resting on the vegetable matter. Regarded in this manner, the seismic theory may be made to account for all the observed phenomena, while the solfatara theory, or the theory of falling stones, leaves, as we have seen, much to be explained. For my part, with such observations as have been brought before us, I prefer to believe that the majority of the holes at Bandai-san were formed by a seismic effort packing up watery strata which here and there burst through the superincumbent strata at points of least resistance, rather than by any of the unusual methods which have been suggested.

Prof. Knott said there were difficulties which prevented him from accepting some of the theories advanced. The argument as to the mud being thrown up on the lower side of the hole would, he thought, apply equally to Prof. Milne's theory, as in any case the mud which was thrown up on the higher side must fall back into the hole while that on the lower side remained. He was inclined to Prof. Milne's belief that there should be a great many holes of different sizes corresponding to different sized boulders. How was it therefore that the the size of the holes was so limited? Those were some of the difficulties regarding the stone theory. Now he would bring forward a theory of his own which was caused by the mention of the pine stump holes. Possibly where stones were found in holes, such holes were made by the digging for pine roots, and the stones discovered might have rolled in during the eruption.

Mr. R. Whittington remarked that the stone theory might

apply to some of the holes, while the water theory might also account for others, but no definite evidence had been produced. Before the latter theory could be proved it would be necessary to discover whether the mud in the holes was similar to the watery stratum underneath.

Professor Sekiya complimented Mr. Odlum on his paper, and considered that he had advanced decisive evidence in support of his theory,

The Chairman did not consider any of the theories advanced sufficiently established by the facts. The presence of mud on the lower side was certainly not more against Professor Milne's theory than in favour of Mr. Odlum's. The question was still left an unsettled one.

Professor Knott enquired what was the ratio of the number of holes in which boulders were discovered to the number of holes investigated.

Mr. Odlum, in the course of his reply, referred to an experiment with paraffin and mercury which he said indicated that his conclusions as to the forms of the holes were correct. As to the argument that the plants taken from beneath the stones should be crushed and not perfect, he informed the meeting that the plants which were removed were immensely crushed, in fact there was nothing but fibre left as his specimens showed. The stones had the appearance of having been recently thrown in the holes, neither were the stones all of one size; there were many small ones, but the larger ones were better suited for investigation. He was delighted to see Professor Milne holding on with such vigour to his theory but he himself could hardly conceive Bandai-san being a sort of watery mountain. To suppose that the holes were made by water was to suppose that the mountain was one of water, and such a mountain could not stand. The holes were both large and small in size, they varied according to the size of the boulder, and those he examined evidenced the cor-

rectness of his theory. Dealing with the theory that the stones might have rolled into holes which were waiting to receive them, he remarked that he should have expected to find the stones on the surface of the hole and not buried several feet below as was the case.

The usual compliments to the lecturer and chairman concluded an interesting meeting.

ON THE DISTRIBUTION OF EARTHQUAKE MOTION WITHIN A SMALL AREA.

BY JOHN MILNE.

[Read January 24th, 1889].

Anyone who has resided for some length of time in a district shaken by earthquakes can hardly have failed in noticing that almost every observer of a shock describes his sensations and experiences differently. One observer may describe a shock as sharp and coming from the north, while his neighbour will declare that it was gentle and the movement was distinctly east and west. In another part of the same city several observers will tell you that neither they nor their families felt any earthquake whatever. On one occasion I remember a shock which was sufficiently strong to cause a number of the members of a small club situated on the east side of Tokio to seek refuge outside, while at several houses not more than three quarters of a mile distant, although careful enquiries were made, nobody could be found who had felt the disturbance.

Another instance of extremely local movement was given me by a gentleman who made enquiries from his friends as to whether they had felt a particular earthquake. One conclusion he arrived at was, that the movement had only been felt by people whose houses were along a particular line running through the city of Tokio. Observations such as these, and of which very many might be quoted, have generally been regarded as attempts to test the credulity of listeners, but the more notes I accumulated respecting the distribution of earth-

quake motion the more I became inclined to the belief that earthquake motion has often been very much more local and peculiarly distributed than is generally supposed.

My curiosity having been excited, in the summer of 1887 I determined by a rough series of tests to approximately determine the extent to which different portions of the city of Tokio were shaken in different earthquakes. To do this I distributed through the city and its suburbs, 134 bundles of post cards. Each card which was addressed to myself, had upon it in English and in Japanese the following request:—" If you or your neighbours feel an earthquake, kindly post this card, giving the *date* and *time* of the shock, and saying whether it was *short, long,* a *tremor* or a *jerk;* were you upstairs or downstairs?"

With each bundle, in which there were 20 cards, there was a letter of more detailed instructions. Many of these bundles were given to members of the Seismological Society or to friends whom I knew took an interest in seismological investigation. For the distribution of the greater number of my bundles of cards I must thank my friend and colleague Professor Sekiya, who took the trouble to write to a hundred or more schoolmasters and others who had a scientific training asking them whether they were willing to undertake the trouble of filling up cards when they experienced a disturbance. To those who sent a favourable reply, bundles of cards were forwarded. I particularly desire to lay stress on the method of distribution, so that it will be understood that the cards were not distributed haphazard but were given to persons who were educated and who were willing and capable of making the necessary observations. The accompanying map (No. 1), which shows a land area measuring six miles from East to West and five miles from North to South, indicates by numbers the positions of the various observers. Those on the western and northern sides of the city were mostly situated

on ground from 50 to 100 feet above sea level, while those on the southern and eastern parts of the town were living on low flat ground which is over-looked by the bluff-like terminations of the high ground. This latter part of the city is intersected by many moats and canals, and by one large river.

In a paper entitled "The Stone Age in Japan; with Notes on Recent Geological Changes which have taken place," published in the Journal of the Anthropological Institute, May, 1881, I have given four vertical sections of borings in the low ground of Tokio, and a quantity of evidence showing that during recent times at the head of Tokio bay, the land, partly by elevation and partly by silting has rapidly been encroaching on the sea.

In a paper on "Stone Implements and Prehistoric Remains in Japan," read before the Asiatic Society of Japan, November 11th, 1879, evidence that the low ground of Tokio is of comparatively recent origin is supplemented with a map showing how since A.D. 1028 the coast line has progressed southwards.

The following are a few examples of vertical sections in different parts of Tokio which I have taken from an account of the geology of Tokio, kindly furnished to me by Mr. Y. Wada, Director of the Geological Survey.

The position of some of these sections are indicated on Map No. 1 by letters corresponding to the alphabetical order given with the sections.

The depths given are in shaku (1 shaku=·994 ft.) and indicate the depth at which any particular layer terminates, reckoned from the surface.

A.—ASUKAYAMA, OJI.

1.	Loam	32.5
2.	Clay	37.5
3.	Sand and shingle with a few patches of clay..............	102.5
4.	Clay and sand with fossils	110
5.	Tuff with fossils ...	127½
6.	Tuff, no fossils	

B.—GONGEN, NEDZU.

1.	Loam	35
2.	A thin layer of pumice Sandy loam............ Sand and shingle...	80
3.	Clay.....................	82½
4.	Sand and shingle ...	

C.—OCHANO-MIDZU.

1.	Loam with a thin layer of pumice ...	50
2.	Clay	55
3.	Sand and shingle...	95
4.	Clayey tuff to 127.5	

D.—NISHIKATAMACHI, KOMAGOME.

1.	Loam with thin layer of pumice.........	27.5
2.	Clay.....................	32.5
3.	Sand and shingle to 65	

E.—HOHEIKOSHO.

1.	Loam with thin layer of pumice	37.5
2.	Clay	42.5
3.	Sand and shingle to 62.5	

F.—YAKUŌ-IN.

1.	Loam with thin layer of pumice	52.5
2.	Clay.....................	65
3.	Sand to 70	

G.—KIRISHITAN-SAKA, KOISHIKAWA.

1.	Loam	70
2.	Clay	72.5
3.	Sand and shingle with a little clay to 100	

H.—ROKUTENCHO, KOISHIKAWA.

1.	Loam with a band of pumice...........	47.5
2.	Clay.....................	50
3.	Sand and shingle with clay	87½
4.	Clay to 92	

I.—TOYOKAWA-MACHI, TAKATA.

1.	Loam with a band of pumice	62 5
2.	Clay	65
3.	Pebbles to 135	

J.—KAMI-TOMISAKA-CHO, KOISHIKAWA.

1.	Loam	45
2.	Clay......	54
3.	Pebbles to 107.5 ...	

K.—AKAGI TEMPLE.

1.	Loam with band of pumice..............	60
2.	Sand and shingle...	100

L.—TSUKUDO, USHIGOME.

1.	Loam with pumice...	32.5
2.	Clay.....................	35
3.	Sand and shingle to 57.5	

M.—ATAGO, SHIBA.

1.	Loam	30
2.	Clay	35
3.	Sand and shingle...	85
4.	Clay	90
5.	Tuff to 110...........	

N.—ENOKICHO, AKASAKA.

1.	Loam with clay	30
2.	Clay	37.5
3.	Sand and shingle with clay to 85......	

O.—MUKOJIMA.

1. Sand and earth ...	3.05	8. Sand, earth with oysters	26.41
2. Ditto, but more sandy	6.80	9. Sand and earth......	28.60
3. Ditto, with coarse sand.................	7.90	10. Ditto with clay	40.31
4. Coarse sand	11.97	11. Clay with sand	49.17
5. Sand and pebbles	13.85	12. Ditto, with coarse sand	57.19
6. Sand and oyster shells	18.13	13. Sand and clay	60.39
7. Ditto, with pebbles	23.63	14. Sand	61.59

P.—NAKUSA, NEAR YEITAIBASHI.

1. Clay	5.50	5. Blue earth	16.77
2. Coarse sand	7.75	6. Ditto, but watery ...	19.47
3. Blue sand, clayey...	9.35	7. Soft clay	43.02
4. Ditto, with pebbles	14.88	8. Ditto, but harder ...	60.69

BORE HOLE IN FUKAGAWA.

Earth	96	Coarse sand	234
Shingle	108	Shingle	246
Earth and sand	126	Sand	270
Shingle	144	Blue clay	273
Loam sand	153	Sand	384
Blue clay	168	Blue sand	420
Sand	180	Sand	430
Shingle	222	Sand	546
Blue clay			603

Four borings near the old Naval College in Shiba, after from 5 to 8 feet of soil, give up to a depth of 40 or 50 feet alternate layers of soft mud, clay, and sand.

From these sections we may conclude that the hilly ground on the West and Northern side of Tokio which rises abruptly about 80 or 90 feet above the low ground, consists of about 40 feet of friable loam, 2 or 3 feet of clay and say 40 feet of sand and shingle. Below this we meet with the hardened clay-like tuff similar to that so well exposed near Yokohama. This tuff which may be looked upon as a soft rock, would therefore crop out near the base of the Bluffs. From this point the tuff dips down beneath the low ground, where it is covered with a thin layer of earth followed by thicker beds of sand and mud extending to a depth of several hundred feet.

The rock beneath the low ground of Tokio, with the exception of one or two places, as for instance near Shinbashi, is covered with a layer of softer material than that which covers it on the hills, and this layer is about twice the thickness of that upon the hills.

On map No. 1 a natural section is given two *ri* in length extending from the high ground to the low ground, showing the relationship of the alluvium and rock to the surface contour.

Seventy-five observers were situated on high ground and fifty-nine on low ground. In addition to the regular postcard observation, I occasionally received notes from friends especially interested in earthquakes, and the records from the Chirikioku (Imperial Meteorological Bureau) where there is a well equipped seismological observatory and several officers whose duty it is to attend to the registration of earthquakes. Another observatory on the high ground is that of Professor Sekiya. I also received occasional communications from friends living on the low ground and from Professor Sekiya's second observatory situated at Hitotsubashi. The total number of my correspondents therefore amounted to nearly 150.

Before proceeding to the enumeration of the records which were obtained, which commenced on November 15th, 1887, and terminated in May 6th, 1888, it is necessary to epitomize several important results respecting the distribution of earthquake motion obtained during previous years without which, to the majority of readers the records might in many instances appear as a series of contradictory observations.

Observations possibly Explanatory of the Distribution of Earthquake of Motion in Tokio.

The first, and so far as I am aware the only, experiments having a definite relation to and possibly explanatory of the observations made in Tokio are a series of experiments which extended over a period of two years, which I described under the title of a Seismic Survey (Trans. Seis. Soc., Vol. X. p. 1 to 36.)

The object of these experiments was to determine on a piece of ground about 900 feet in diameter, how far the motion of a given earthquake recorded upon one portion of it differs from that recorded upon other portions. The results obtained were exceedingly astonishing. On one side of the ground the motion might be quick and small, while on the other side, which was relatively soft, the motion was slow and large. No two parts of the same area yielded identical diagrams of the same disturbance, in fact they were at times so different that it appeared possible that an indifferently built house on one side of the area might be shattered whilst on the other side a similar house might remain unhurt. The instruments employed were in every way similar and when placed side by side they yielded, either for actual earthquakes or for artificial disturbances, like results. These observations explained why diagrams of earthquakes obtained by residents on the low ground near the centre of Tokyo were always larger than those obtained by persons like myself situated upon the high ground. Amongst the many other results yielded by these experiments it was shown that earthquakes with a long period, although the amplitude might be large, might pass across an area without attracting the attention of persons unprovided with instruments. A remarkable example among many disturbances of this discription which I have called slow earthquakes was one recorded on March 25th, 1884, which although it yielded a remarkably fine diagram, was not, so far as I can learn, felt by any of the many people who resided near me—one or two persons, however, observed that at the time of the disturbance lamps were swinging. Another result demonstrated by actual measurement was, as might be anticipated, that the diagrams indicating the longest period had been recorded upon the softest ground, and we might therefore conclude that it would be upon the softest ground where people would have the greatest chance of being moved back and forth without noticing any motion. In moderately severe earthquakes, however, the range of motion was on

soft ground so much greater than it was upon hard ground, that so far as destructive motion (acceleration) was concerned this became more than it was upon hard ground.

From this it might be argued that moderately severe earthquakes passing across the whole of Tokio would be felt as much upon the soft low ground as they would upon the hard, dry ground. For very small earthquakes, however, still resting our argument upon results obtained from the Seismic survey, this same law will not hold, because with small earthquakes it was sometimes found that the record for amplitude and acceleration was less than that obtained upon hard ground, In these cases it appeared as if the soft ground absorbed the motion. This would lead to the conclusion that small earthquakes might not be felt upon the low soft ground of Tokio while they might be felt upon the high ground which is hard. Another observation which also bears upon the results to be described in this paper is that the experiments made in the seismic survey distinctly showed that at any given station there was a relation between period and amplitude, the period increasing very rapidly with the amplitude until the amplitude became large, after which the period ceased to increase or only increased very slowly. On different kinds of ground it is probable that this relationship between period and amplitude will be different, and it is not unlikely that upon hard ground the critical point when period practically becomes constant will be reached much more quickly than it is upon soft ground, but on soft ground the maximum period will have a far greater amplitude than will be experienced for the maximum period on hard ground. Farther, although the maximum period in soft ground may be greater than the maximum period reached upon hard ground, the amplitude of motion in the soft ground will so far as destructive effect is concerned more than counterbalance the destructive effect on hard ground where although the period is short the amplitude of motion is more than correspondingly small.

In large earthquakes the destructive effect on soft ground may therefore be greater than it is on hard ground, whilst small earthquakes may not be recorded on the soft ground. A somewhat similar series of results respecting the relation of amplitude to period are indicated in a paper on Seismic Experiments (Trans. Seis. Soc., Vol. VIII., p. 1-82).

In interpreting the observations made in Tokio, although we are all aware that when a moderately destructive shock has occured in Yokohama it has always been the houses on the hills or hard ground which have most severely suffered, it must be remembered that this is contrary to general experience. At the time of the great Lisbon earthquake, the destruction of Port Royal, the Ansei earthquake in Tokio, the earthquakes at Cassamicciola, and in fact in nearly all great disturbances the buildings on the low soft ground have almost invariably suffered most severely.

A set of observations which have been of value in approximately determining the area over which a shock of any magnitude has extended, are those made at the Meteorological Bureau (Chirikioku).

In 1881 I distributed bundles of fresh cards over the Northern portion of the Japanese Empire much in the same way as post cards were distributed over Tokio. ("On 387 earthquakes, observed during two years in North Japan, by John Milne.—Trans. Sei. Soc., Vol. VII., Part II., p. 1-87.") From the records received I was able to draw maps showing the area over which any given shock had extended, and in this way to determine the portions of northern Japan which were most shaken. This work has now been undertaken by the Meteorological Bureau in Tokio who have now more than 600 post card stations distributed throughout the Empire.

From these records, which the Director of the Observatory Mr. Arai Ikunosuke, has kindly placed at my disposal, I have in many instances been able to state whether a shock was only felt in Tokio or whether it was a shock having a wide distribution. The area over which a shock has been felt is given in square *ri* (1 square *ri* = 5.95 square miles). With these preliminary observations I will now proceed to an enumeration of the records.

Observations on Earthquakes

Felt in different parts of Tokio in 1887-1888, the records being obtained from post-cards.

1.—November 15th, 1887.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
65	Kōjimachi.	4.5 p.m.	feeble	long	Upstairs.
116	Kōjimachi.	3.55 p.m.	very feeble	—	Ground floor.
109	Tsukiji, French Legation.				Not felt.
54	Yotsuya ...	3.55 p.m.	feeble	about 1m.	Ground floor.
6	Kōjimachi.	? 5.00 p.m.	very feeble	short	Ground floor; only felt by two out of six persons present.
4	Akasaka...	4.00 p.m.	feeble	long	Ground floor.
108	Azabu......	3.54.20 p.m.	feeble	slow vibrations for 30s.	Ground floor.
3	Azabu......	3.55 p.m.	feeble	35s.	Ground floor.
	Hongo, Sekiya ...	3.52.28 p.m.			
	Hitotsubashi, Sekiya	3.52.28 p.m.			
	Kokadaigaku		amp .2mm.		A long slow motion (Milne).
	Chirikioku.	3.54.51 p.m.	amp .4mm. period 2.4	2m.	Direction E. 26° 30′ S.

This earthquake was not felt at Chôoji, Takanawa, or in Shinagawa, or by any of the servants in the French Legation, No. 18, Tsukiji.

It was felt in Iidamachi, Kojimachi, also at No. 9, Torizaka, Azabu.

This earthquake is one which extended over a large area of country (1,460 square *ri*) and therefore it might be expected that it ought to have been recorded by the greater number of observers living in Tokio. As a matter of fact it was only felt at 10 places, and these are all situated on the high ground on the western side of Tokio or along a north and south line

extending from Shiba in the south to Yotsuya and Koishikawa in the north. It was also recorded at three observatories. The probable explanation for this curious distribution of motion that was sensible lies in the fact that the wave frequency (4 waves in 10 sec.) was small or the period of any given wave was long (nearly 2½ seconds). On the hard high ground, the period being a little quicker than on the soft low ground, it was only those living on the high ground who noticed the movement.

2 AND 3.—NOVEMBER 20TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
123	Azabu	0.3 p.m.			
28	Fukugawa.	0.6 p.m.	pretty strong	10s.	Ground floor.
28	Kanda ...	0.3 p.m.	pretty strong	30 40s.	Upstairs.
44	Fukagawa.	0.1 p.m.	feeble	1m.	Ground floor.
45	Fukagawa.	0.2 p.m.		? 3m.	Upstairs.
86	Honjo	0.5.30 p.m.	feeble	2s.	Ground floor.
84	Honjo	0.4 p.m.	feeble	2m.	Ground floor.
84	Honjo	0.4 p.m.	feeble	2s.	Ground floor.
35	Honjo	? 11.57 a.m.	feeble	5s.	Ground floor.
41	Honjo	0.3 p.m.	feeble	20s.	Ground floor from north-east.
46	Honjo	0.3 p.m.	feeble	very short	Ground floor.
78	Honjo	0.5 p.m.	pretty strong	5-6s.	Ground floor.
80	Honjo	11.50 a.m.	feeble	2m.	Ground floor.
87	Asakusa ...	0.1 p.m.	feeble	30s.	Ground floor.
89	Honjo	0.2 p.m.	pretty strong at first and feeble afterwards	40s.	Ground floor from south-west.
63	Kyobashi ..	0.5 p.m.	feeble	30s.	Upstairs.
75	Asakusa ...	0.2 p.m.	very feeble	4s.	Upstairs.
76	Asakusa ...	0.2-3 p.m.	feeble	1-2m.	Ground floor from south-west.
70	Shitaya ...	0.3 p.m.	very strong at first and feeble at the end	30s.	Ground floor from south-east to north-west.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
70	Shitaya ...	0.2.30 p.m.	very strong at first and ending feeble	15s.	Ground floor from north-west.
70	Shitaya ...	0.5 p.m.	very feeble	1m.	Ground floor.
72	Shitaya ...	0.4 p.m.	pretty strong	40s.	Ground floor.
72	Shitaya ...	0.2 p.m.	feeble	40s.	Ground floor.
52	Shitaya ...	0.3 p.m.	pretty strong	about 30s.	Ground floor.
58	Hongo ...	0.0 p.m.	pretty strong	about 3m.	Ground floor.
92	Kanda ...	0.8.9 p.m.	pretty strong	about 1m.	Upstairs.
104	Kanda......	0.3 p.m.	tremor	1m.	Downstairs.
64	Koishi-kawa......	0.5 p.m.	strong at first	about 20s.	Ground floor.
64	Koishi-kawa......	0.2.1 p.m.	strong	short 3s.	Ground floor from north-south.
68	Koishi-kawa......	0.5 p.m.	pretty strong	5s.	Ground floor from north-east.
33	Kanda ...	0.2 p.m.	very feeble	5s.	Upstairs.
35	Honjo......	0.3 p.m.	slow	30s.	Ground floor on hill at Omori. But the same was the case at No. 35.
36	Kanda ...	0.3 p.m.	pretty strong	10s.	Upstairs.
42	Kanda ...	0.4.35 p.m.	strong	20s.	Downstairs from north-west.
67	Kanda ...	0.0 p.m.	feeble at first then strong lastly feeble	5m. 30s.	Upstairs from south-east to north-west.
67	Koishi-kawa......	0.3 p.m.	very feeble	about 10s.	Ground floor.
31	Nihon-bashi	0.2 p.m.	pretty strong		Ground floor.
82	Nihon-bashi	0.3 p.m.	a jerk		Upstairs.
27	Kyobashi..	0.3 p.m.	feeble	about 6s.	Ground floor.
106	Kyobashi..	1.6 p.m.	jerky	25 or 30 seconds	Downstairs from E. to W.
113	Kyobashi..	0.3 p.m.	short and violent	about 2s.	
124	Kyobashi..	0.3 p.m.	tremor	about 30s.	Upstairs.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
18	Kōjimachi.	0.7 p.m.	feeble	about 40s.	Ground floor.
37	Kōjimachi.	0.5 p.m.		1m.	Ground floor.
111	Kōjimachi.	0.4 p.m.			
54	Ushigome.	0.0 —	pretty strong	about 1m. 3s.	Ground floor on low marshy place.
55	Nihon-bashi	0.9 p.m.	pretty strong	about 1m.	Ground floor from south.
54	Yotsuya ...	0.0 —	strong	1m. 5s.	Ground floor.
54	Yotsuya ...	9.40 p.m.	very feeble	1m.	Feeble shock again at 9.40 p.m. on the same day.
95	Yotsuya ...	0.2 p.m.	feeble	3s.	Felt while walking in garden.
99	Yotsuya ...	0.1.30 p.m.	pretty strong	1m. 2-3s.	Ground floor.
4	Akasaka ...	0.2.31 p.m.	pretty strong first and ending feebly	40s.	From south to north ground floor.
4	Akasaka ...	9.55 p.m.	very feeble	slow	From south-north ground floor.
6	Akasaka ...	11.48 a.m.	feeble	2s.	From south-north ground floor.
6	Akasaka ...	0.0 p.m.	pretty strong at first	2m.	From south-north ground floor.
25	Akasaka ...	0.3 p.m.	feeble	3s.	From south-north ground floor.
1	Azabu	0.23 p.m.	pretty strong at first	1m.	From south-north ground floor.
2	Azabu	0.3 p.m.	very feeble	about 30s.	From south-north ground floor.
3	Azabu	0.2.20 p.m.	pretty strong	30s.	From south-north ground floor.
5	Azabu	0.30 p.m	pretty strong	2m. 30s.	From south-north ground floor.
11	Azabu	0.3 p.m.	feeble	1m.	From south-north ground floor.
12	Azabu	0.1 p.m.	pretty strong at first	1ms. 30s.	From south north ground floor.
18	Azabu	0.2-3 p.m.	feeble	35-36s.	Downstairs from south.
108	Shiba	0.3 p.m.	sharp jerk	about 10s.	Ground floor.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
8	Shiba	0.2 p.m.	pretty strong	20s.	
8	Shiba	0.1 p.m.	pretty strong	30s.	Upstairs.
47	Shiba	0.4 p.m.	pretty strong	70s.	Ground floor from N.E.
114	Shiba	0.5 p.m.	very feeble	10s.	Ground floor.
	Hongo (Sekiya)..	0.02.31			
	Hitotsu-bashi (Sekiya)..	0.02.31			
	Kokadai-gaku		.2 mm.		Motion chiefly E. and W.
	Chirikioku	0.02.31 p.	amp .2 period .5	45s.	Direction N. 17° E.
	Yokohama	9.45.00 p. at noon			Very slight.

122.—At 12.2-3.0 p.m. in the English Church at Iigura, two or three slight waves followed by three or four more decided motions were felt. There was no jerk. The duration was about 8 or 10 seconds. The movement was similar at Chôoji, Takanawa.

101.—At 12.3.0 p.m., a very slight disturbance of extremely short duration was felt, the observer being downstairs (Bamba-cho, Shinagawa).

105.—At 12.2.0 in the English Church at Iigura, a short sharp shock lasting about 20 sec.

108.—At 12.3.0 p.m., a sharp shock—a jerk. Duration 10 sec. The observer on the ground floor, Azabu.

115.—About noon. A tremor of short duration felt downstairs. Things shook considerably and glass and crockery rattled. No. 1, Tsukiji. Kiobashi.

116.—At 12.5.0 p.m. A tremor lasting 10 sec. felt while on the verandah downstairs. Kojimachi.

117.—At 12.3.0. A sharp shock felt downstairs.

5.—At 12.4.0 p.m. A horizontal slight shock. Movement

E.-W. Duration 1m. 30s. It was accompanied by a noise from the E. The observer downstairs. Akasaka.

107.—At 11.57.0 a.m. Apparently imperceptible to one standing, but felt distinctly while sitting on mats downstairs. Tangomaçhi, Akasaka.

107.—At 12.2.0 p.m. A feeble earthquake lasting about 5s. was felt while downstairs. Many people did not feel it. No. 22, Shinmeicho, Shiba.

110.—At 12.5.0 p.m. A short tremor-like disturbance. (Dutch Legation, Shiba.)

The earthquake at 0.2.31 p.m. is one which not only extended over a large area (1,360 square *ri*) but the period of movement appears to have been short. It is therefore natural that it should have been felt throughout Tokio.

As the shock at 9.45.0 p.m. was only felt at two places on the west side of Tokio and at the Chirikioku, it was probably of local origin and in no way connected with the disturbance at midday. Its area is given as 670 square *ri*.

4.—November 23rd.

No.	Lcoality.	Time.	Intensity.	Duration.	Remarks.
55	Ushigome.	6 p.m.	feeble	about 2s.	Downstairs.
117	Azabu......	6 p.m	feeble		Downstairs felt 2 slight shocks.
4	Akasaka...	6.10 p.m.	feeble	about 10s.	Downstairs.
117	Kōjimachi.	5.59 or 6 p.m.	slight tremor		Downstairs.
96	Minami Toshima..	6.5 p.m.	feeble		
	Chirikioku	6.05.00 p.			Very slight.

The Chirikioku maps only show that Tokio was shaken.

We have here another example of a shock only felt on the high ground upon the W. and N.W. side of Tokio, in Akasaka, Azabu, and Kojimachi. On the N.E. side of Tokio it seems too feeble even to have been recorded by instruments. It was not felt in districts surrounding Tokio.

5.—NOVEMBER 26TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
10	Yotsuya ... Yokohama	5.6 a.m. 4 a.m.			 N.E.-S.W.

6.—NOVEMBER 27TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
2	Azabu......	2.11 p.m.	gentle tremor	5m.	Downstairs.

Kobudaigaku—On each of two static seismographs an indication of .1 mm.

7.—NOVEMBER 30TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
84	Honjo......	9.25 a.m.	feeble	about 4s.	Downstairs.
127	Kyobashi..	9.26 a.m.	very feeble		Upstairs.
49	Ushigome.	9.22½ a.m.	feeble	about 30s.	Upstairs.
41	Minami-Katsu-shika......	9.25 a.m.	feeble	about 30s.	Downstairs north to south.
87	Honjo......	9.25 a.m.			Downstairs school.
85	Minami-Katsu-shika......	9.40 a.m.	feeble	about 1 sec.	
25	Shitaya ...	9.30 a.m.	pretty strong	about 1 minute	Downstairs.
100	Hongo	9.28 a.m.	slight tremor		Downstairs.
60	Kita-Toshima..	9.24 a.m.	feeble	5 sec.	Downstairs school.
125	Koishi-kawa	9.24 a.m.	series of short shocks	30 sec.	
131	Kanda......	9.30-10 a.m.	pretty strong		Downstairs.
31	Nihon-bashi......	9.25 a.m.	feeble	40 sec.	This felt at Takarada School Kyobashi upstairs.
31	Nihon-bashi......	9.15 a.m.	feeble		Downstairs.
116	English Legation, Kōjimachi.	9.21 a.m.	long tremor		Downstairs.
4	Akasaka...	9.25 a.m.	feeble	30 sec.	Downstairs south-north.
112	Shiba	9.25 a.m.	feeble		

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
114	Shiba	9.28 a.m. 9.24.18 a.m.	very feeble	7 or 8 sec.	New form of pendulum machine felt at J. M. C. observatory.
	Hongo (Sekiya)..	9.24.18			
	Hitotsu-bashi......	9.24.18			
	Chirikioku	9.24.18 a.	amp 1.3 period 1.2	1m. 30s.	S.S.E.-N.N.W.
	Yokohama	9.23.0 a.			N.E.-S.W. slight.

127.—No. 33, Tsukiji, at 9.26 a.m., a slight shock, hardly perceptible.

122.—Shiba, Chôoji, 9.25 a.m., a long, slow, slight earthquake, but as there was much wind it is not absolutely certain that it was an earthquake.

110.—Shiba, Kiridoshi, a long tremor, not very strong. There was much wind.

Kobudaigakko, Toranomon—Saw the tremor machine working violently but could not feel any motion, amplitude .3 mm.

131.—Surugadai, Suzukicho—Felt at 9.30 by a servant downstairs. It was a long tremor without jerk.

125.—The University, Hongo, at 9.24 a.m. a series of short shocks were felt while in a wooden out-building.

At No. 6, Kaga Yashiki, it was felt.

Miogadani not observed.

132.—Masagocho, Hongo, at 9.27 a.m. a tremor lasting 1½ minute. High Normal School, felt upstairs in large brick building, but not felt upstairs in a wooden building.

Although this shock disturbed a large area (1,710 square *ri*), in Tokio it was only practically felt along a north and south line slightly to the west of the central part of the city extending from Shiba on the south to Koishikawa on the north. The length of the period, 1.2 sec., would explain why it was

unnoticed upon the flat ground, but it does not explain why it was not felt upon the high ground towards the west. There were 6 waves in 10 seconds.

8.—DECEMBER 3RD.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
34	Kanda......	4.50 p.m.	feeble	4 minutes	Downstairs.
45	Fukagawa.	5 a.m.	tremor	2 seconds	Upstairs.

9.—DECEMBER 3RD.

45	Fukagawa.	6.23 a.m.	feeble	2 seconds	Upstairs (Time doubtful).
3	Azabu	0.58 a.m.	sudden shock	very short	Downstairs.
		0.58 a.m			
	Kōjimachi.	0.58 a.m.	feeble	4 seconds	Upstairs machine indicated 2 mm.
	Chirikioku	0.57.16 p.		15 sec.	Very slight 15 mm.
	University Observatory				Earthquake recorded
	7 Nagatacho.........	0.58	very slight		S.W. and N.E. very slight oscillation of lamps.
	Kobudaigakko ...		.2 mm.		Felt upstairs very slight.

This shock, which was not felt in districts outside Tokio, is remarkable for the small area over which it was felt within the city itself, only being recorded at three neighbouring stations in Azabu. The record from Fukagawa is either a mistake or refers to another disturbance.

10.—DECEMBER 6TH.

55	Ushigome .	3.23 p.m.	sudden shock pretty strong	about 4 or 5s.	Downstairs.
123	Azabu	3.24 p.m.	feeble		
95	Minami Toshima..	3.26 p.m.	very feeble	1 sec.	Downstairs.
111	Kojimachi.	3.18 p.m.			
108	Azabu	3.24 p.m.	feeble	15 sec.	

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
3	Azabu	3.23 p.m.	feeble		Downstairs Longitude 139° 44′ 30″ E. 35° 39′ 17″ N.
45	Fukagawa.	1.49 a.m.	feeble		Downstairs.
45	Fukagawa.	4.31 a.m.	feeble		Downstairs.
54	Yotsuya ...	3.25	pretty strong	4 minutes	Downstairs.

108.—Azabu, at 3.24 p.m., quick, slight vibrations lasting 15 sec. The first shock was the most severe.

Kobudaigakko—Shock felt.

We have here an example of another shock only felt on the western part of Tokio, and although two observers report it as being pretty strong, it does not appear to have affected the instruments at the observatory in the centre of the city or those in the north-east.

11.—DECEMBER 7TH.

	Hongo (Sekiya)..	at night	slight		

12.—DECEMEER 8TH.

3	Azabu	8.2 p.m.	little tremor		Downstairs.
123	Azabu	8.2 p.m.	feeble		
108	Azabu	8 p.m.	feeble	4 or 5 sec.	
118	Azabu	8.8 p.m.	feeble	2 sec.	Ground floor.
5	Azabu	8.2 p.m.	very feeble	30 sec.	Ground floor.
4	Akasaka ..	8 p.m.	feeble	1 or 2 sec.	Downstairs.
4	Akasaka ..	8.2 p.m.	pretty strong	10 sec.	Downstairs.
19	Yotsuya ...	8 p.m.	feeble		Downstairs.
54	Yotsuya ...	7.40 p.m.	strong	1 minute	Downstairs.
54	Yotsuya ...	7.50 p.m.	strong	1m. 40sec.	Downstairs.
54	Yotsuya ...	9.15 p.m.	feeble	4 sec.	Downstairs.
90	Yebara ...	8.1 p.m.	pretty strong	about 1m.	Downstairs west-north to east-south.
55	Ushigome.	8 p.m.	pretty strong	5 sec.	Downstairs.
54	Yotsuya ...	7.30 p.m.	strong	1 minute	Downstairs.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
129	Kanda......	8.2 p.m.	short tremor		Downstairs.
49	Ushigome.	8.1.49 p.m.	feeble	15 sec.	Downstairs.
49	Ushigome.	8.2.20 p.m.	pretty strong	38 sec.	Downstairs.
41	Minami-Katsu-shika......	8.3 p.m.	feeble	30 sec.	Downstairs north-west.
100	Hongo.....	8 p.m.	feeble		Downstairs.
104	Kyobashi..	8 p.m.	sharp shock		
123	Azabu......	8.40 p.m.	feeble		
	Hongo (Sekiya)..	8.02 p.			
	Hitotsu-bashi......	8.02 p.			
	Chirikioku	8.02.00 p.	amp .4 period .5	50 sec.	S.W.-N.E.

104.—Hongo, F. W. Strange. Although the observer was writing at a desk in a quiet room at 8 p.m. no shock was felt, neither did 10 other people in the house feel it. In Tsukiji it was quite sharp and also in Azabu.

132.—Hongo, Masagocho, at 8.3 p.m. a tremor lasting 25 sec. was felt while downstairs.

131.—Surugadai, Suzukicho, while upstairs moderate vibrations lasting 10 sec. were felt. Very small vibrations preceded for about 30 seconds the stronger movements. No jerk.

Kobudaigakko—Movement short and gentle.

122.—Takanawa, Chooji, at 5 p.m. a very slight trembling, lasting a few seconds. A minute later a more decided motion also lasting a few seconds.

110.—Shiba Kiridoshi, 8.2 p.m. a short, sharp jerk. Lamps moved.

This earthquake was only felt in the west and north parts of the city, being strongest in the western and north-western parts of this area.

The 8 p.m. shock was only felt at Asawa a few miles N.E. from Tokio.

13.—DECEMBER 11TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
	Hitotsu-bashi......	9.55.47			
	Chirikioku	9.55.47 p.			Very slight.

14 AND 15.—DECEMBER 14TH.

	Chirikioku	11.55.12 a.	amp .2 period 2.3	2m. 12s.	S.-N. It is clear that this was not felt on account of the long period. It is a good example of a slow earthquake.
		10.55.09 p.	amp .3 period .2	2m. 30s.	S.S.E.-N.N.W. It is clear that this was not felt on account of the long period. It is a good example of a slow earthquake.
	Hongo (Sekiya)..	11.55.12 a.			
	Hitotsu-bashi......	11.55.12 a.			

The shock at 11.55.12 (or 12.40 at C.) according to the Chirikioku maps, was only felt at Kamakura.

16.—DECEMBER 16TH.

96	Minami-Toshima ...	8.30 a.m.	pretty strong		
59	Nihon-bashi......	8.30 a.m.	pretty strong	about 1m.	Upstairs.
75	Asakusa ...	8.32 a.m.	pretty strong	5 seconds	Downstairs.
69	Koishi-kawa......	8.30 a.m.	pretty strong		To north - east from south-west.
94	Kita-Toshima ...	8.30 a.m.	feeble	30 sec.	Downstairs.
45	Fukagawa.	8.28 a.m.	feeble	1 minute	Upstairs.
119	Kōjimachi, German Legation...	8.30 a.m.		30 sec.	Downstairs.

No	Locality.	Time.	Intensity.	Duration.	Remarks.
116	Kōjimachi, British Legation........	8.30 a.m.	tremor and jerk		Downstairs.
13	Azabu......	8.25 a.m.	pretty strong	1m. 10s.	Upstairs.
22	Shiba	8.39 a.m.	pretty strong	38 sec.	Downstairs (time is uncertain).
	Honjo......	8.15 a.m.	pretty strong	2 sec.	Downstairs.
3	Azabu......	8.28 a.m.	pretty strong		Downstairs.
31	Nihonbashi......	8.25 a.m.	pretty strong	30 sec.	Downstairs.
34	Kanda......	8.35 a.m.	pretty strong	3m. 27s.	Downstairs.
53	Ushigome.	8.40 a.m.	pretty strong	2m.	Downstairs.
107	Shiba	8.20 a.m.	strong tremor		Glass doors rattled sharply.
129	Kanda......	8.28 a.m.	long jerk		Upstairs and downstairs.
121	Shiba	8.31 a.m.	sharp shock		Downstairs.
76	Kyobashi..	8.34 a.m.	strong	1 minute	Upstairs, south from north.
83	Honjo......	8.36 a.m.	strong	20 sec.	Downstairs.
14	Azabu......	8.31 a.m.	strong	40 sec.	Downstairs.
111	Kōjimachi	8.28 a.m.			
51	Yotsuya...	8.35 a.m.	strong	5 second	Downstairs.
93	Shitaya ...	8.30 a.m.	feeble	1m. 5s.	Downstairs.
5	Kanda......	8.28 a.m.	strong		Downstairs.
106	Kyobashi..	8.30 a.m.	tremor	20 sec.	Upstairs.
104	Hongo	8.30 a.m.	tremor	2 minutes	Duration determined by motion of water in a vessel, and noise from windows.
54	Yotsuya ...	8.25 a.m.	strong	2 minutes	Downstairs.
67	Hongo	8.50 a.m.	strong	3 minutes	Downstairs.
125	Koishikawa......	9.27 a.m.	strong and jerky	short	Upstairs.
59	Hongo ...	8.30 a.m.		1 minute	Downstairs.
117	Nihonbashi		strong jerk	30 sec.	
131	Surugadai.	8.30 a.m.	strong, no jerk		Upstairs.
123	Azabu	8.25 a.m.	strong		

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
47	Shiba	8.27 a.m.	strong	1 minute	Downstairs twice shook.
101	Shinagawa	8.30 a.m.	short and jerky	10 sec.	Downstairs W.S.W. to E.N.E.
132	Hongo ...	8.32 a.m.	tremor	1 minute	Upstairs in brick building.
85	Minami Katsu-shika	8.30 a.m.	strong	2 sec.	Downstairs, from west-south (?)
107	Kojimachi.	8.25 a.m.	long and with a jerk		Downstairs.
46	Minami Katsu-shika	8.30 a.m.	strong	20 sec.	Downstairs.
10	Yotsuya ...	8.28 a.m.	strong	30 sec.	Downstairs.
54	Yotsuya ...	8.40 a.m.	strong	1m. 30s.	Downstairs from south-east (?)
11	Akasaka ..	8.30 a.m.	strong	15 sec.	Downstairs from E.E.N. (?)
36	Kanda ...	8.27 a.m.	strong	1 minute	Upstairs from E.
72	Kita Toshima..	8.28 a.m.	strong	2 minutes	Downstairs.
115	Tsukiji	8.35 a.m.	short, sudden, strong jerk		Downstairs.
4	Akasaka...	8.29 a.m.	strong	1 minute	Downstairs.
35	Honjo	8.34 a.m.	strong	2s. or 3s.	Downstairs.
55	Kōjimachi.	8.30 a.m.	strong	1 minute	Downstairs.
55	Kyobashi..	8.20 a.m.	strong	3 minutes	Downstairs from east-south (?)
90	Yotsuya ...	8.25 a.m.		1 minute	
12	Azabu	8.25 a.m.	feeble	30 sec.	Downstairs.
28	Fukagawa.	8.29 a.m.	strong	1 minute	Downstairs from west to east.
25	Akasaka...	8.28 a.m.	strong	1 minute	Downstairs.
41	Minami-Katsu-shika	8.30 a.m.	strong	1 minute	Downstairs from north.
114	Shiba	8.35 a.m.	strong	6s. or 7s.	
133	Kōjimachi, Nakani-bancho ...	8.27 a.m.	a long shock	4 sec.	Upstairs.
95	Minami-Toshima..	8.20 a.m.	strong	10 sec.	Downstairs from E.N.E. to W.S.S.
		8.29 a.m.		10 sec.	
	Hongo, Sekiya ...	8.29 a.m.			

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Hitotsu-bashi......	8.29 a.m.			
	Chirikioku	8.28.21 a.m.	amp 2.5 period 1.5	2 sec.	W.N.W. - E.S.E. vertical motion. amp. ·3 period .4
	Yokohama	8.30 a.m.		10 sec.	N.W.-S.E.

Kojimachi, British Legation—In a brick bungalow downstairs at 8.29 a.m. there was a horizontal motion, slow and without jerks, commencing lightly and gradually increasing in intensity—the rapidity of oscillations increasing as the disturbance went on. Direction E.N.E. to W. by S. This shock was typical of shocks so often felt in Tokio.

129.—Surugadai, at 8.23 a.m. a severe shock—a long jerk. Bells rang. Felt upstairs and downstairs.

121.—Shiba, Sannai—A sharp short shock at 8.31 a.m.

110.—Shiba, Kiridoshi—At 8.25, a sharp shock as if from below, followed by long strong tremors.

117.—Iidamachi, Kojimachi, at 8.30 a.m. a heavy blustering shock. The noise was remarkable, sounding like the moving of furniture overhead.

122.—Takanawa, Chôoji, at 8.30 a.m. rather strong shock lasting 30 sec. No jerk, but the bells rang. Downstairs.

Koishikawa Riding School, a strong jerk.

118.—Azabu, 8.30 a.m. a long strong shake.

126.—The University, Hongo, 8.25 a.m., a short shake and then a longer one. Sensible for 30 sec.

106.—Tsukiji, No. 32, at 8.30 while upstairs a shock followed by a tremor lasting 20 or 30 sec.

109.—Tsukiji, French Legation, a shock tolerably strong and long. Felt upstairs.

This shock which was felt over a large area (2,260 square *ri*) although its period was fairly long, was felt throughout Tokio and apparently with equal intensity in different parts of

the city but by rather more observers on high ground. There were 8 waves in 10 seconds.

17, 18, AND 19.—DECEMBER 17TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
95	Asakusa ...	6.23 a.m.	feeble	3s.	Downstairs.
123	Azabu......	0.15 a.m.	feeble		
130	Kyobashi..	6.32 a.m.	two short jerks	15 sec.	Upstairs.
94	Kita-Toshima..	5 a.m.	feeble		Downstairs.
3	Azabu......	11.44 a.m.	pretty strong		Downstairs.
107	Shiba	6.20 a.m.	tremor		Downstairs.
12	Azabu......	6.18 a.m.	feeble		Downstairs.
114	Shiba	6 a.m.	feeble	4s. or 5s.	
114	Shiba	11.30 p.m.			
125		6.17 a.m.	tremor	short	Upstairs.
72	Shitaya	0.17 a.m.	feeble	30s.	Downstairs.
111	Kōjimachi.	6.18 a.m.			
122	Shiba, Chooji.....	0.7 a.m.	jerk		Downstairs.
4	Akasaka...	0.17 a.m.	feeble		Downstairs, direction of north-south.
4	Akasaka...	6.17.30 a.m.	feeble	1s.	Downstairs, direction of north-south.
8	Shiba	0.19 a.m.	feeble	14s.	Upstairs, from east-south to north-west.
28	Fukagawa.	0.17 a.m.	feeble	7s. or 8s.	Downstairs.
31	Nihon-bashi......	0.17 a.m.	feeble		Downstairs.
31	Nihon-bashi......	6.16 a.m.	feeble		Downstairs.
3	Azabu......	0.20 a.m.	feeble		Downstairs.
45	Fukagawa.	0.17 a.m.	feeble		Downstairs.
129	Kanda	0.19 a.m.			
129	Kanda	6.19 a.m.			
4	Akasaka...	11.47 p.m.	jerk	about 20.	Downstairs.
121	Shiba	11.42 p.m.	short sharp shock	2s.	
	Kōjimachi.	0.20 a.m.		25s.	
		0.17 a.m.		1s.	
		6.15 a.m.	slight shock		
133	Kōjimachi.	0.10 a.m.	long shock	5s.	Upstairs.

No. Locality.	Time.	Intensity.	Duration.	Remarks.
133 Kōjimachi.	11.45 p.m.	slight shock	4s.	Upstairs.
132 Hongo	11.47 p.m.	tremor		
95 Minami-Toshima..	11.38 p.m.	pretty strong	3s.	Downstairs.
75 Asakusa ...	11.40 p.m.	feeble	5s.	Downstairs.
111	11.30 p.m.	pretty feeble	4s. or 5s.	
132 Hongo	5.30 a.m.	jerk		
22 Shiba	11.50 p.m.	feeble	2s.	Downstairs.
72 Shitaya	11.43 p.m.	feeble	5s. or 6s.	Downstairs.
11 Azabu......	0.5 a.m.	short, pretty strong		Downstairs.
31 Yotsuya ...	9.15 a.m.	long strong		Downstairs.
54 Kanda	9.30 a.m.	strong	long	Upstairs.
54 Kanda	12.15			
Hongo (Sekiya)..	0.17.8 a.			
Hitotsu-bashi (Sekiya)..	6.17.22 a.			
Chirikioku	0.17.08 a.		10s.	Slight.
Chirikioku	6.17.22 a.			Very slight.
	11.41.14 p.	amp .2 period .6	10s.	E.-W.
Yokohama	11.40.0 p.		8s.	N.W.-S.E.

95.—Yotsuya, at 11.38 a.m.

95.—Asakusa, at 11.45 p.m.

Kobudaigakko—At 12.20.0 a.m. slight shock.

Kobudaigakko—At 6.15 a.m. slight shock.

117.—Kojimachi, Iidamachi, 12.17.0 a.m. two sharp shocks felt in bed upstairs. They were felt by the servants downstairs, but not by a visitor.

Kojimachi, 7 Nagatacho—12.16.0 a.m. a sharp shock lasting 25 sec. Motion horizontal.

Kojimachi, English Legation—0.17.0 a.m. distinct earthquake tremor, direction E.W. Duration 1 or 2 sec.

108.—Azabu, 0.20.0 a.m. sharp decided shock, more of a jerk than a tremor, lasting 5 sec. downstairs.

115.—Tsukiji, American Legation, 12.10 night, a long shock

which seemed to come from below. Upstairs in a wooden building.

121.—Shiba, 11.42.0 p.m. short sharp shock preceded for 2 sec. by a deep rumbling sound.

121.—Shiba, 0.18.0 a.m. short sharp shock like the previous shock.

109.—Tsukiji, French Legation, 12.20 a.m. a light short shock.

109.—Tsukiji, French Legation, 11.40 p.m. very feeble shock.

118.—Azabu, 11.45 p.m. a sharp shock with tremor.

132.—Masagocho, Hongo, 11.47 p.m. last night a sharp jerk followed by a tremor.

Masagocho, Hongo—6.20 a.m. a tremor and jerk.

129.—Surugadai, 12.19 a.m. slight shock.

Surugadai—6.19 a.m. slight shock.

The 0.17.08 a.m. disturbance, although felt over 720 square *ri*, in Tokio was with but three exceptions only felt in the western and northern part of the city, or from Takanawa (Shiba) on the south to Koishikawa in the north. At three places it was short and sharp as if from below.

The 6.17.22 a.m. shock was in Tokio practically felt over the very same area as the 0.17.08 a.m. disturbance. It also extended over a large area. At three places it was felt as a jerk.

The 11.41.14 p.m. disturbance did not extend over a large area, but was only felt in Tokio, and this with but one exception at places along a north and south line like the 0.17.08 a.m. shock. In Shiba it was sharp and preceded by a noise.

20.—December 19.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Komagome	11 p.m.	feeble		Doubtful.
	Hitotsubashi	6.0.12			
	Chirikioku	6.00.20 p.	very slight		

According to maps this shock was only felt in Tokio.

21.—DECEMBER 21ST.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
4	Nagatacho	2.8 p.m.	feeble		
	Akasaka...	2.6 p.m.	feeble		
	Kokadai-gaku	2.7 p.m.	very slight		
	Hongo (Sekiya)..	2.5.55 p.			
	Hitotsu-bashi (Sekiya)..	2.5.55 p.			
	Chirikioku	2.05.55	very slight		

This shock which was only felt in Tokio, with the exception of observations at observatories was only felt at two places on the west side of the city.

22.—DECEMBER 22ND.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Fukagawa.	1.19 p.m.	feeble	1s.	Upstairs.

23 AND 24.—DECEMBER 24TH.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
45	Fukagawa.	5.6 a.m.	feeble	1s.	Upstairs, doubtful shock.
	Fukagawa.	12.3 a.m.			
	Hitotsu-bashi	7.51.30 a.			
	Chirikioku	4.09.41 a.			Very slight.
	Chirikioku	7.51.38 a.	amp. .12 period 2	about 1m.	S.W.-N.E. a slow earthquake, and therefore not felt.

This 4.09.41 shock extended over 272 square *ri*.

25.—DECEMBER 31ST.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Chirikioku	1.24.45 a.			Very slight.

This shock was only felt in Tokio.

26.—JANUARY 1ST.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
126	Hongo	3.25	jerk	1sec.	
	Chirikioku	3.31.38 p.	very slight		Very slight.

This shock was only felt at the observatories in Tokio. It extended over 1,460 square *ri*.

27.—JANUARY 9TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
45	Fukagawa.	1.41 a.m.	feeble		Upstairs.

28.—JANUARY 11TH.

55	Ushigome.	8.53 a.m.	feeble	2s. or 3s.	Downstairs.
		8.42 a.m.	feeble		
116	Kōjimachi.	8.50 a.m.	slight tremor		
125	Hongo	8.50 a.m.	series of shocks	50s.	
130	Kyobashi..	8.54 a.m.	slight	2s.	Downstairs.
13	Azabu	8.52 a.m.	feeble	1m. 15s.	
111	Kōjimachi.	8.51 a.m.			
108	Azabu	8.49 a.m.	pretty strong	1m. 40s.	Downstairs.
4	Akasaka, Aoyama..	8.50 a.m.	feeble		On the road.
109	Kyobashi, Tsukiji ...	8.50 a.m.	tremor		Upstairs.
3	Azabu	8.50 a.m.	pretty strong		Short shock downstairs.
110	Shiba, Kiridoshi.	8.55 a.m.	tremor		
114	Shiba	4.18 a.m.	short		Downstairs.
85	Myoga-dani				Not felt.
	Nagata-cho, Kōji-machi	8.42	slight		Felt as two small shocks, stronger in Azabu.
	Hongo (Sekiya)..	8.50.30			
	Hitotsu-bashi	8.50.30			
	Chirikiokū	8.50.36 a.	amp .4 period 1.8	1m.	E.S.E. - W.N.W. Rather long period to have been so well felt.
	Yokohama	3.25.0 p.m.			N.E.-S.W.
	Yokohama	8.55.0 a.			N.E.-S.W.

This disturbance which extended over a large area (1,480 square *ri*), was in Tokio practically only felt along a N. and S.

line extending from Shiba through Kojimachi, that is to say in the west side of the city.

Its period was moderately long. There were 7.5 waves in 10 seconds.

29.—JANUARY 14TH.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
87	Honjo	8.15 a.m.	feeble	short	Downstairs (?)
116	Kōjimachi.	5.30 p.m.	slight	short	
55	Ushigome.	5.30 p.m.	feeble	5s.	Downstairs.
5	Kyobashi..	5.33 p.m.	feeble	5s.	Downstairs.
5	Azabu	5.36 p.m.	feeble		
45	Fukagawa.	5.29 p.m.	feeble	2m.	Upstairs.
113	Surugadai.	5.40 p.m.	feeble		Downstairs.
	Nagata-cho, Kōjimachi	5.32 p.m.	tremor		Preceded by very slight tremors.
	Chirikioku	5.31.55 p.	slight	15 sec.	E.W. slight vertical motion.

This shock which was only felt in Tokio, was only observed by one or two observers living on the N.W. side of the city.

30.—JANUARY 15TH.

4	Akasaka ...	6.13.0(?)p.	feeble		

This shock was felt for some distance along the coast of Kadzusa.

31.—JANUARY 16TH.

4	Akasaka ...	3.35 a.m.	feeble	5s. or 6s.	

32.—JANUARY 27TH.

3	Azabu	10.4 a.m.	feeble	short	Downstairs.
	Hitosu-bashi	10.7.0 a.			
	Chirikioku	10.05.33 p.	very slight	about 10s.	N.-S.

This shock was felt over 180 square *ri*.

33, 34, 35, AND 36.—FEBRUARY 2ND.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
133	Kojimachi.	1.20 p.m.	strong	long about 3m.	
133	Kojimachi.	2.28 p.m.	strong		
133	Kojimachi.	3.5 p.m.	feeble		
133	Kojimachi.	4.47 p.m.	strong	quick	
63	Asakusa ...	1.15 p.m.	feeble	20s.	Downstairs.
126	Hongo	3.42 p.m.	pretty strong	1m.	
96	Ushigome .	1.30 p.m.	feeble		
96	Ushigome .	3.45 p.m.	pretty strong		
132	Hongo	1.20 p.m.	strong	long	Upstairs.
132		3.45 p.m.	feeble		Upstairs.
18	Shiba	1.17 p.m.	strong	1m.	Downstairs.
11	Azabu	1.20 p.m.	strong	3m.	Downstairs.
11	Azabu	3.45 p.m.	feeble	3s.	Downstairs.
55	Ushigome.	1.20 p.m.	strong	3m.	Downstairs.
116	Kojimachi.	3.45 p.m.	strong		
46	Honjo	0.16	strong	1m. 20s.	Downstairs.
42	Kojimachi.	1.15 p.m.	strong	1m. or 2m.	Upstairs south to north.
122	Kojimachi.	3.45 p.m.	strong	1m.	Shoji rattled for 1m. Preceded by a rumbling sound. No jerk.
111	Kojimachi.	3.4 p.m.			
90	Yotsuya ...	1.18 p.m.	strong	3m.	Shocked from N.
90	Yotsuya ...	3.43 p.m.	feeble	1m.	Shocked from N.
116	Kojimachi.	1.15 p.m.	tremor	20s.	Downstairs.
5	Shiba	1.16 p.m.		40s.	Downstairs.
122	Chooji, Shiba	1.15 p.m.	strong	long	Commenced gently.
130	Shiba	1.25 p.m.	jerk	8s.	Downstairs.
108	Azabu	3.41 p.m.	sharp shock	30s. to 1m.	Motion quicker than at 1.15 p. downstairs.
108	Azabu	1.15 p.m.	feeble	1m.	Downstairs.
32	Nihon-bashi	1.35 p.m.	strong	2m.	Upstairs.
129	Kanda	3.40 p.m.	tremor	long	Downstairs.
130	Shiba	3.50 p.m.	jerk	3s.	Downstairs.
106	Kyobashi ..	1.40 p.m.	feeble	1m.	Downstairs.
106	Kyobashi ..	4.4 p.m.	tremor	30s.	Downstairs.
45	Fukagawa.	0.16 p.m.		3m.	Upstairs.
40	Fukagawa.	1.15 p.m.	strong	40s.	Downstairs.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
40	Fukagawa.	3.35 p.m.	feeble	7s. or 8s.	Downstairs.
108	Azabu	1.16 p.m.	strong	3m.	Downstairs.
28	Fukagawa.	1.25 p.m.	strong	2m.	Downstairs.
52	Shitaya.....	1.30 p.m.	strong	25s.	Upstairs.
110	Kiridoshi, Shiba	1.18 p.m.	hard tremor	long	Lamps swinging.
111	Kojimachi.	1.15 p.m.			
120	Shiba	1.15 p.m.	strong	long	Easy motion, did not rattle glass.
	Honjo	1.23 p.m.	strong	1m.	Downstairs.
115	Tsukiji	1.15 p.m.	strong	1m.	Motion easy, downstairs.
114	Shiba	1.15 p.m.	strong severe	long	Horizontal motion.
129	Kanda	1.17 p.m.	tremor	long	Downstairs.
72	Shitaya.....	1.25 p.m.	strong	long	Upstairs.
45	Fukagawa.	3.45 p.m.		1m.	Upstairs.
31	Kyobashi..	1.45 p.m.	strong	3m.	Downstairs.
126	Hongo	1.11 p.m.		long 40s.	Gentle oscillation.
	Nagatacho	1.15 p.m.	moderate		Lamps described ellipse NE.-SW.
		3.40 p.m.	moderate		Lamps did not swing, but wobbled; apparently vertical. Not so strong as 1.15 shock.
	Hongo (Sekiya)..	1.15.15 p. 2.24.0 p.			
	Hitotsu-bashi......	1.15.15 p. 2.24.0 p.			
	Chirikioku	1.15.15 p.	amp 3.0 period 3.7	3.48	W.N.W. - E.S.E. Vertical motion amp. .5.
		2.23.46 p.	.7 1.4	1.49	E.W.
		3.00.14 p.	very slight		
		3.41.27 p.	3.8 2.4	4.05	W.S.W.-E.N.E.
	Yokohama	1.16.0 a. 3.45.0 p.		8 sec.	E.W.

The 1.15.15 p. shock shook 3,440 square *ri*. There were 5 waves in 10 seconds.

The 2.23.46 p. shock shook 1,680 square *ri*. There were 7 waves in 10 seconds.

The 3.00.14 p. shock shook 730 square *ri*.

The 3.41.27 p. shock shook 2,630 square *ri*. There were 4.5 waves in 10 seconds.

37.—FEBRUARY 3RD.

No.	LOCALITY.	TIME.	INTENSITY.	DURATION.	REMARKS.
114	Shiba	3.15 p.m.	feeble	7s. or 8s.	
111	Kōjimachi.	2.35 p.m.			
112	Shiba	2.36 p.m.	tremor	3s. or 4s.	Upstairs.
108	Azabu	2.40 p.m.	slight jerks	3s. each	Two slight shock with an interval of a minute.
133	Kōjimachi.	2.37 p.m.	strong		
132	Hongo......	1.35 p.m.	feeble		Upstairs.
	Nagata-cho, Koji-machi	2.35.0	slight	short	Sudden and preceded by a short noise.
	Hongo (Sekiya)..	2.37.20			

38.—FEBRUARY 5TH.

4	Akasaka ..	1.15 p.m.	strong	long	Downstairs.
4	Akasaka ..	3.41 p.m.	strong	long	Downstairs.
133	Kōjimachi.	1.5 p.m.		1m.	
112	Shiba	0.53 p.m.	jerk	short	Upstairs. S.W. N.E.
55	Ushigome.	pretty (?) before 1 p.	feeble	6s. or 7s.	Downstairs.
4	Akasaka ..	0.50 a.m.	feeble		Downstairs.
116	Kōjimachi.	0.30 a.m.	tremor	short	
120	Shiba	7 a.m.			North to south.
	Nagata-cho, Kōji-machi	0.52 a.m.	gentle		
	Hongo (Sekiya)..	0.50.56 a.			
	Hitotsu-bashi......	0.50.56 a.			
	Chirikioku	0.50.56 a.	amp 1.6 period 2.1	about 1m.	S.W.-N.E.
	Yokohama	0.53.0 a.			

This shock disturbed a large area (9,670 square *ri*). There were 7 waves in 10 seconds.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Hongo (Sekiya)..	11.33.44 a.			
	Hitotsu-bashi......	11.33.44 a.			
	Chirikioku	11.33.44 a.	slight	25 sec.	S.-N.

Only felt in Tokio.

45.—February 15th.

104	Hongo......	3.20 p.m.	short jerk		
	Hongo (Sekiya)..	3.20.30 p.			
	Chirikioku	3.43.38 p.	very slight	30 sec.	E.-W.

It shook 460 square *ri* (?)

46.—February 17th.

111	Kojimachi.	12.40 p.m.			
	Chirikioku	0.16.17 p.	very slight	50 sec.	E.-W.

This shock was felt in Tokio and to the N.E. in Sakura and Narita. It shook 170 square *ri*.

47.—February 18th.

45	Shiba	6.45 p.m.	feeble	2m.	Downstairs.
41	Honjo......	6.22 p.m.	feeble		
	Chirikioku	6.13.45 p.	very slight	15 sec.	E.-W.

This shock was felt in Tokio and to the North and East in Mohara, Sakura, Sakai, Asaw (?), and Mito, shaking 570 square *ri*.

48.—February 22nd.

	Kobu-daigakko.	10.25.0	slight		
	Nagata-cho, Kōji-machi.....	10.27 a.m.	very slight		
	Shinbashi..	11.10	slight tremor		
	Chirikioku	10.24.43 a.	·7 3·2	1.30	E.-W. slow earthquake.
	Hongo (Sekiya)..	10.25.0			
	Hitotsu-bashi......	10.25.0			

This shock was felt in Tokio and all down the coast from Kamaishi a distance of over 200 miles. Shaking 5,220 square *ri*. There were 4 waves in 10 seconds.

49.—February 23rd.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Chirikioku	11.10.50 p.	very slight	10 sec.	S.-N.

This shock was only felt in Tokio.

50.—February 24th.

134	Kōjimachi.	2.7 a.m.	slight	1 sec.	Upstairs.
	Chirikioku	2.07.06 a.	very slight		E.-W.
	Hongo (Sekiya)..	2.26.0 a.			
	Hitotsu-bashi (Sekiya)..	2.26.0 a.			

It shook 580 square *ri*.

51 and 52.—March 1st.

5	Shiba	9 50 p.m.	feeble	5s.	Upstairs.
	Hongo......	9 a.m.	feeble		
	Nagata-cho, Kōji-machi	3·30	feeble		
60	Hongo......	9.59 p.m.	jerk	short 2s.	Downstairs.
11	Azabu	10.5 p.m.	strong	20s.	Downstairs.
126	Hongo......	9.54 p.m.	feeble	10s.	
45	Fukagawa.	9.55 p.m.	feeble		Upstairs.
87	Honjo	9.45 p.m	feeble	short 3s.	Downstairs.
117	Kōjimachi.	9.50 p.m.	slight	short	Upstairs.
68	Koishi-kawa	9.55 p.m.		3s.	Downstairs.
31	Nihon-bashi	9 55 p.m.	strong	short	Downstairs.
134	Kōjimachi.	9 57 p.m.	jerk and tremor		Preliminary tremor upstairs.
119	Kōjimachi	10 p.m.	tremor	4s.	Downstairs.
133	Kōjimachi	9.52 p.m.		long	
122	Chōoji, Shiba......	10 p.m.	jerk		
122	Chooji, Shiba......	3·30 p.m.	slight tremor		
110	Shiba	10.4 p.m.	tremor		

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Hongo (Sekiya)..	3.30.0 p.			
	Hitotsu-bashi......	3.30.0 p.			
	Chirikioku	3.30.15 p.	slight	1.15	W.S.W.-E.N.E.
		9.54.12 p.	slight	30 sec.	S.-N.
	Yokohama	10.30.0 p.			

The shock at 9 p.m. was only felt in Tokio. The 3.30 shock was felt in Tokio and to the North and North-West at Ashikaga, Sakai, and Mito. The 10.30 shock was felt at Tokio, Ashikaga, Sakai, Mito, and Sakura.

The 3.30 p. shock shook 580 square *ri*, and the 9.54 p. shock shook 670 square *ri*.

53 AND 54.—MARCH 9TH.

	Nagata-cho, Koji-machi.....	5 a.m.	pretty strong	2s.	Preliminary tremors.
133	Kōjimachi.	5 a.m.	strong		
133	Kōjimachi.	10.20 p.m.	feeble		
134	Kōjimachi.	10.18 p.m.	feeble		Upstairs.
117	Ushigome.	4.50 a.m.	sharp	short	Upstairs, also felt downstairs.
125	Koishi-kawa......	4.57 a.m.	sharp	continuous	Upstairs.
90	Yebara	4.54 a.m.	strong	20s.	
132	Hongo	5 a.m.			Upstairs.
7	Akasaka...	4.58 a.m.	strong	about 1m.	Downstairs.
31	Nihon-bashi......	4.55 a.m.	strong	short	Downstairs.
94	Kita-Toshima..	5 a.m.	strong	4m.	Downstairs.
118	Azabu......	4.56 a.m.	jerk	15 sec.	Two shocks in succession and sound of an explosion, ground floor.
22	Shiba	4.50 a.m.	strong	short 3s.	Downstairs.
110	Shiba	4.56 a.m.	jerk		As if the house was lifted.
121	Shiba	4.57 a.m.	sharp	2m.	Preceded by a loud rushing sound up and downstairs.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
55	Ushigome.	4.58 a.m.	strong	2m.	
108	Azabu......	4.49 a.m.	strong	2m.	Downstairs.
129	Kanda, Surugadai...	4.53 a.m.	two jerks	short	Downstairs.
119	Kojimachi.	5 a.m	tremor	30s.	Downstairs.
122	Chooji, Shiba.....	5 a.m.	tremor		A rumble like artillery wagons, a great bump and several shakes.
127	Kyobashi..	4.55 a.m.	sharp jerk		Upstairs, preceded by a heavy report like an explosion.
134	Kojimachi.	4.57 a.m.	sharp		Upstairs.
116	Kojimachi.	5 a.m.	sharp	short	Preceded by a noise.
114	Shiba	5 a.m.	strong	5s. or 6s.	
	Hongo (Sekiya)..	4.56.26 a.			
	Hitotsubashi......	4.56.26 a. 10.17.0 p.			
	Chirikioku	4.54.16 a.	amp .4 period .2	25 sec.	N.N.W.-S.S.E.
	Chirikioku	10.7.1 p.	very slight		
	Yokohama	4.58.0 a.			S.E.-N.W. slight.

The 5 a.m. and the 10.7 p.m. shocks extended over a large area.

The 10 p.m. shock probably not felt in Tokio on account of its being slow period, Tokio being on the outer edge of the disturbance.

The 4.54.16 a. shock shook 620 square *ri*. The 10.17.01 p. shock shook 1,470 square *ri*.

55 and 56.—March 16th.

	Nagata-cho, Kojimachi.....	6 a.m.			
	Nagata-cho, Kōjimachi.....	6.45 a.m.			
96	Minami-Toshima..	6.40 a.m.	feeble		Downstairs.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
110	Kiridoshi, Shiba	6 a.m.	tremor	long	
110		6.45 a.m.	strong	long	
31	Nihon-bashi	6.40 a.m.	tremor	short	Downstairs.
35	Honjo	5.58 a.m.	feeble	short 2s.	Downstairs.
47	Shiba	6.45 a.m.	feeble	2m.	Downstairs.
118	Azabu	5.58 a.m.	jerk	short	
118	Azabu	6.46 a.m.	strong		
117	Ushigome.	5.55 a.m.	slight	long	
117	Ushigome.	6.43 a.m.	strong		
87	Honjo	5.57 a.m.	strong	short	Downstairs.
87	Honjo	6.45 a.m.	feeble	short	Downstairs.
119	Kōjimachi..	4 a.m.	slight	short	Downstairs.
119	Kōjimachi.	6.45 a.m.	tremor	10 sec.	Downstairs.
127	Kyobashi..	6.44 a.m.	jerk	8 sec.	Upstairs, sharp shock.
125	Koishi-kawa	6.45 a.m.	strong tremor		Upstairs.
	Surugadai.	5.58.0 a.			Second shock not felt on Surugadai.
134	Kōjimachi.	5.58.0 a.	smart jerk		
134	Kōjimachi.	6.45 a.	gentle		
132	Hongo ...	6.0.0 a.			
132	Hongo ...	6.45 a.			
	Hongo (Sekiya)..	5.58.2 a.			
	Hitotsu-bashi	5.58.2 a.			
	Chirikioku	5.58.02 a.	amp .2 period .8	30 sec.	S.E.-N.W.
	Chirikioku	6.43.32 a.	amp .4 period .8	2.50	S.E.-N.W.
	Yokohama	6.0.0 a.			E.-W.
	Yokohama	7.0.0 a.			S.W.-N.E.

The 5.58.02 a. shock shook 1,990 square *ri*, and the 6.43.32 a. shock also shook 1,990 square *ri*.

17.—March 17th.

87	Honjo	7.55 p.m.	feeble	short	Downstairs.
41	Honjo	6.45 a.m.	feeble		North-South.
41	Honjo	8 p.m.	feeble	30 sec.	W.S.W. to E.N.E.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Chirikioku Yokohama	7.55.36 p. 7.0.0 p.	very slight		S.E.-N.W.

This shock only felt in Tokio.

58.—April 1st.

	Chirikioku	6.17.08 a.	very slight		

59.—April 3rd.

17	Kanda......	8.24 p.m.		3m.	Upstairs.

60.—April 5th.

11	Azabu	2.50 p.m.	strong	long	Downstairs.
73	Osatogori..	2.30 p.m.	strong	2m.	Downstairs.
114	Shiba	2.27 p.m.	strong	1m.	
112	Shiba	2.31 p.m.	jerk	3 or 4 sec.	Upstairs, severe tremors.
109	Kōjimachi.	2.30 p.m.	tremor	long	
55	Ushigome.	2.30 p.m.	strong	1m. 20sec.	Upstairs.
118	Azabu	3.35 p.m.	tremor	long	A jerk in the middle.
75	Asakusa ...	2.32 p.m.	strong	1ms. 10s.	Upstairs.
31	Nihon-bashi......	2.32 p.m.	strong	long	Downstairs.
17	Nihon-bashi......	2.28 p.m.	strong	2m.	Downstairs.
93	Kita-Toshima..	2.37 p.m.	strong	6 sec.	Downstairs.
76	Kyobashi ..	2.35 p.m.	strong	2m.	Downstairs.
110	Shiba	2.31 p.m.	tremor	long	Severe.
119	Kōjimachi.	2.30 p.m.	tremor	1m.	
56	Fukagawa.	2.27 p.m.	very strong	1m.	Downstairs.
108	Azabu	2.34 p.m.	strong	1m. 30s.	Downstairs, severe, vibrations short and sharp.
28	Fukagawa.	2.34 p.m.	strong	2m.	Downstairs.
90	Yebara	2.28 p.m.	strong	1m.	
126	Honjo......	2.30 p.m.	strong	long	
10	Hongo	2.30.10 p.	strong	1m. 30s.	
10	Kōjimachi.	2.30.10 p.	strong	2m. 20s.	

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Hitotsu-bashi......	2.30.29 p.			
	Hongo ...	2.30.29 p.	period .7 amp 1.2	1.30	Vertical motion slight.
	Chirikioku	2.30.29 p.	period 1.2 amp .7	2m.	S.E.-N.W. Vertical motion amp. .5 period .2
	Hitotsu-bashi......		period .9 amp .2	2.20	Vertical motion .5

This shock extended over 4,060 square *ri*. There were 14 waves in 10 seconds.

61.—April 8th.

	Chirikioku	2.22.32 p.	very slight		

62.—April 11th.

	Chirikioku.	11.06.43 p.	very slight		
	Yokohama	2.30.0 p.			S.E.-N.W.

63.—April 14th.

134	Kōjimachi.	11.17.0 p.	slight	short	Upstairs.

This shock only felt in Tokio.

No. 134 being a particularly careful observer, there is good reason for believing that at this time there was really a shock.

64.—April 26th.

96	Minami Toshima..	2.22 p.m.	feeble		Downstairs.
	Hitotsu-bashi......	2.10.30 p.			

65.—April 27th.

No.	Lcoality.	Time.	Intensity.	Duration.	Remarks.
	Chirikioku	8.34.34 a.	amp .2 period 1.5	2m.	S.W.-N.E. Slow earthquake.

This shock shook 660 square *ri*.

66.—April 29th.

90	Yebara	10.25 a.m.	strong	3m.	
75	Asakusa...	9.57 a.m.	strong	2m.	Downstairs.
5	Shiba	10 a.m.	strong	40 sec.	Upstairs.
118		10 a.m.	tremor and jerk		Noise heard before the earthquake; heavy shock as if from an explosion.
94	Kita-Toshima..	10 a.m.	strong	2m.	Downstairs.
129	Surugadai.	10.0 a.m.	severe jerks	long	Downstairs.
100	Hongo......	10 a.m.	strong	long	Downstairs.
56	Honjo	9.57 p.m.	strong	long 2m.	Upstairs.
	Kyobashi..	10.4 a.m.			
121	Shiba	10.2 a.m.	sharp	long	Water in pond agitated. Trees swaying.
114		10 a.m.	strong	3 or 4m.	
28	Fukagawa.	10.2 a.m.	strong	2m.	Downstairs.
31		10.2 a.m.	strong	1m.	Upstairs.
109	Kōjimachi.	10 a.m.	strong	long	
	Hongo......	10.0.33 a.			
	Hitotsu-bashi	10.0.33 a.			
	Chirikioku	10.0.33 a.	amp 5.6 period .8	8.0	S.E.-N.W. Vertical motion amp. 1.5 period .6
	Yokohama	10.03.0 a.			S.W.-N.E.
	Kanagawa	10.0.0 a.	amp. 6mm.		Strong and long.

This shock shook 5,080 square *ri*. There were 13 waves in 10 seconds.

67.—April 30th.

No.	Locality.	Time.	Intensity.	Duration.	Remarks.
	Chirikioku	5.44.38 a.	very slight		E.-W.

This shock shook 1,110 square *ri*.

68.—May 5th.

	Chirikioku	8.52.24 p.	very slight		

69.—May 6th.

104	Hongo (Strange)	2.54 p.m.	jerk	short	
104		2.59 p.m.	jerk	short	
104		3 p.m.	jerk	short	

Analysis of Records.

Altogether I distributed 2,010 post cards. Out of these between November 15th, 1887, and May 5th, 1888, a period of nearly 6 months, 103 observers sent in 496 records. Thirty-one observers, 14 of whom lived on the high ground and 17 lived on the low ground, although it seems impossible that they should not have felt at least one of the 69 shocks recorded, did not return a single card.

The balance of unused cards amongst actual observers up to May 5th was 1,064. Many of these since that date have been returned, but they have not been used in the following investigations, inasmuch as other observers had by May 5th exhausted the stock of cards with which they were provided.

The 496 records were made as follows:—370 came from 61 observers living on high ground, that is upon the western and northern side of Tokio, while 126 records came from 42 observers living on the low ground.

The average number of records per observer on the high ground was 6, while upon the low ground the average was 3.

The greatest number of observations was made at station number 4 upon the west side of Tokio, where by placing the record of several earthquakes upon one card, fifteen cards contained the record of 21 shocks.

On map No. 1 the hilly, high ground is indicated by shading and the stations by numbers. The short horizontal strokes give the number of observations made at the station to which they are contiguous. Stations with a circle round them are the non-observers.

This map clearly shows that the greatest number of earthquakes was observed by residents on the high ground.

The disturbances which were only felt in Tokio were at least 25 in number. In 8 other cases, as the shock was only recorded by one observer, it is possible that a mistake may have been made in observation. Such observations are accompanied with a note of interrogation.

The numbers of these earthquakes are, 4, 5 ?, 6 ?, 8, 9, 10, 11, *13*, *14*, *15*, *20*, 21, 22 ?, 24, *25*, 27 ?, 29, 31 ?, 37, 39 ?, 42, 43 ?, 44, *49*, 57, *58* 59 ?, *61*, *62*, 63, 64, *68*, 69.

Disturbances which were only felt at an observatory are in *italics*. All these earthquakes, with the exception of No. 57, which is said to have been felt upon the east side of the city, were only felt upon the hilly, hard ground upon the western and north-western side of the city. They are shown in map No. 2.

The disturbances which were felt in Tokio and which in addition also shook a large tract of country surrounding the city, in some cases the whole coast line for at least 200 miles, were 36 in number.

The numbers of these disturbances are 1, 2, 3 7, 12, 17, 16, 18, 19, 23, 26, 28, 30, 32 33, 34, 35, 36, 38, 40, 41, 45 46, 47, 48, 50, 51, 52, 53, 54, 55, 56, 60, 65, 66, 67.

From this it appears that about 41 per cent. of the shocks felt in Tokio are of local origin.

The 30 shocks which were felt in Tokio, and which shook a large tract of country may be subdivided as follows :—

1. Shocks which were felt all over Tokio. These are 6 in number, namely, numbers 2, 16, 19, 33, 60 and 66.

2. Shocks which practically were only felt upon the hilly, hard ground upon the west side of Tokio. These are 30 in number, namely, numbers 1, 3, 7, 12, 17, 18, 28, 30, 32, 34, 35, 36, 38, 40, 41, 46, 48, 50, 51, 52, 53, 54, 55, and 56.

(Note.—Shocks 26, 45, 65 and 67 were only recorded at the Observatories. Shocks 23 and 47 were recorded at an observatory and at one or two stations.)

From the above we might conclude that 36 per cent. of the earthquakes which shake an enormous area of ground outside Tokio only shake the hilly part of Tokio itself.

From maps of shocks which shook a large area but only shook the hills on the west side of the city, I find from records kept by Mr. E. J. Pereira of Yokohama, which lies from Tokio about 16 miles S.S.W., that at least 10 such shocks were felt in Yokohama. Had Mr. Pereira been provided with a proper instrument, or had he had the assistance of other observers, it is probable that he might have recorded a still greater number of this particular kind of disturbance.

I.

Shocks which shook a large area of country and the whole of Tokio :—

The No. of the Shock.	Period in Seconds.	Average Period.	Area Shaken in Sq. Ri.
2	.2	1.1	1362
16	1.5	1.25	2260
19	.6	—	—
83	3.7	2.	3440
60	1.2	.7	4060
66	.8	.77	5080
Average	1.33	.76	3240

II.

Shocks which shook a large area of country, but which only shook the hilly part of Tokio :—

The No. of the Shock.	Period in Seconds.	Average Period.	Area Shaken in Sq. Ri.
1	2.4	2.5	1460
3	—	—	670
7	1.2	1.66	1710
12	.5	—	—
17	—	—	720
28	1.8	1.3	1480
32	—	—	180
34	1.4	1.4	1680
35	—	—	730
36	2.4	2.2	2630
38	2.1	1.4	9670
40	—	—	160
41	—	—	880
46	—	—	170
48	3.2	2.5	5220
50	—	—	580
51	—	—	580
52	—	—	690
53	.2	—	520
54	—	—	1470
55	.8	—	1990
56	.8	—	1990
Average	1.52	1.85	1680

From the above tables, which give the period and area shaken by each of these shocks, we see that the shocks which disturbed the whole of Tokio had on the average at the same time each shaken a much larger area than those which were only noticed on the high ground.

Further, those which were felt by the residents on the low ground had on the average a much shorter period than those which were only felt on the high ground.

This latter observation may explain why so many shocks are not recorded on the low ground.

Another explanation is that in many instances a vibratory motion passing beneath Tokio may only reach the surface where the superincumbent soft materials are thin, that is upon

the hills,—the relatively thick deposit of soft material on the low ground absorbing the motion like a buffer.

There were 19 shocks which the instruments at the Imperial Observatory did not record. Out of the 19, however, 8 disturbances had been felt by one observer only, and therefore we cannot say with certainty that there were more than 11 shocks which the Central Observatory failed to observe. On the other hand, there were 10 shocks recorded at the Observatory which were not observed by any of the 134 observers in the city. The most probable reason why 11 earthquakes were unrecorded at the Observatory is because these disturbances were too limited in area to reach the Chiri Kioku. One conclusion we arrive at is that a set of Seismographs located at the observatory in a city like Tokio, no matter how carefully they may be looked after, cannot be expected to record more than 80 per cent. of the total number of earthquakes felt in that city.

Another conclusion resulting from these observations is that residents on the high ground upon the Western and Northern sides of Tokio feel more earthquakes than residents who live upon the low ground towards the South and East. One explanation of this may be that the movement upon the low ground is slower than that on the high ground, but to place this explanation on a more certain foundation it is necessary to make instrumental observations.

A certain number of earthquakes, however, appear to have originated beneath the high ground in the Kojimachi-Akasaka districts, and do not appear ever to have extended to the low ground. This fact will always make the high ground disturbances more numerous than those felt upon the low ground. When I was resident within the area of local disturbances near Toranomon I came to the conclusion that these local shocks might in many instances be recognized by their character, which is that of a small but sudden little tip from beneath, the vibrations, which only continue 2 or 3 seconds, causing hanging lamps to oscillate vertically.

So far as safety is concerned, I am yet of opinion that the high and hard ground is better than the low soft ground, on which earthquake motion, when it is felt, is always greater than it is upon the high ground, and where destruction has almost always been relatively excessive.

REPORT ON EARTHQUAKE OBSERVATIONS MADE IN JAPAN DURING THE YEAR 1886.[*]

(A TRANSLATION, WITH PREFATORY NOTE AND GENERAL OBSERVATIONS, BY JOHN MILNE.)

[READ JANUARY 24TH, 1889.]

PREFATORY NOTE.

The following paper is practically a translation of a report published by the Meteorological Central Observatory in Tokio, Japan. It was drawn up by Messrs. Wada, Outska, Asakusa, and Mayeda, officers in charge of the office where earthquake observation receives special attention, under the general supervision of Mr. Arai Ikunosuke, the Director of the Observatory. The analyses in the first portion of the report refer to observations made at some 650 stations in various parts of the empire, from which after each earthquake a report is sent to the Central Observatory. From the reports on a given earthquake a map is drawn showing the area over which it extended.

The second portion of the report contains the analyses of earthquakes recorded by instruments during eleven years at the Central Observatory.

For the commencement of the general observations in the Japanese Empire, readers may refer to Trans. Seis. Soc., Vol. VII., Part II. "On 387 earthquakes observed during two years (1881-1883) in North Japan, by John Milne." In 1885 this class of observations was taken up by the Imperial Meteorological Observatory and the results of the work for that year were published by Professor S. Sekiya in Trans. Seis. Soc., Vol. X. pp. 57-82. Another paper bearing on this subject is on "The distribution of Seismic Activity in Japan," by J. Milne, Trans. Seis. Soc., Vol. IV. Analyses of instrumental records made in Tokio by the Imperial Meteorological Bureau are to be found in several volumes of the Transactions of the Seismological

Society, one very suggestive paper being "Earthquake Frequency," by C. G. Knott, D.Sc. (Trans. Seis. Soc., Vol. IX., Part I., p. 1-20).

The areas of districts shaken are given in square *ri* (1 square *ri* = 5.95 square miles).

FREQUENCY OF EARTHQUAKES.

The total number of earthquakes which occured during the year 1886 was 472. This amounts to a daily average of 1·3. In 1885 then were 482. A map has been constructed from this total number of earthquakes with the object of showing the comparative frequency of earthquakes in different districts. *(See Plate 1.)* As in the former report, a deep shade of colour shows the districts where earthquakes were most frequent, while lightly shaded portions are the districts where they were less frequent. The figures attached indicate the number of earthquakes that occurred at that spot during the year; for instance 55 in the map means that there were about 55 shakings at that district. The districts where earthquakes were most frequent were Shimotsuke, Musashi, Nemuro, Hitachi, Echigo, as in the last year. Shimotsuke was the highest, being 61. Next in order came Shimōsa, Kushiro (eastern part) Kii, Iwaki, Shinano, Mutsu, Kadzusa, Rikuzen, Kodsuke, Kai, Rikuchiu, Iyo, Satsuma (eastern part) Iwashiro, Ugō, Sagami, Idzumo, Mino, Hiuga, Bungo, Iwami, Chikuzen (named in the order of frequency). Several other provinces not mentioned in the above felt from 1 to 5 shakings. As no report was sent in from the portions left white in the map, that is the western part of Kushiro, Iburi, and Oshima, eastern part of Ishikari, and Iburi, southern part of Shiribeshi, the whole of Hidaka, Tokachi, Teshiro, Kitami, and Kaga, eastern part of Hakase, western part of Ōmi, central part of Harima, Inaba, Hoki, Minasaka, northern part of Idzumo, Oki, eastern part of Sanuki, central part of Awa, eastern part of Tosa, north-western part of Satsuma, and Tsushima, together with small islands surrounding the coast of the main land, we cannot say any-

thing definite about these districts. As we have remarked in the reports of the last year, we cannot at once conclude from such results that there were no earthquakes in those districts. We may, however, say that there was not much difference from the result of the previous year, and that the districts neighbouring the Japan Sea felt few or no earthquakes, and such as may have occurred were too feeble to be recognized without instruments. The ranges of mountains forming the backbone of the mainland, passing between Tosan, Hokuriku, Sanin, and Sanyō, seem to divide this country into two portions, one of which is constantly shaken while the other is almost undisturbed. The fact that we received no report from these districts may be taken as a proof of the absence of seismic disturbance, but there are many doubts about the northern part of Hokkaido. Even in other districts there may have been many earthquakes which have not been reported to us. Very often feeble shocks which occurred during the day when people are engaged at work, or at night when sleeping, or at the time of strong winds, pass by unobserved. To speak definitely about the frequency of earthquakes fuller observations are required.

Relations of Earthquakes to Seasons.

Earthquake seasons are not well defined. The following table shows the monthly number of earthquakes in 1885 and 1886 :—

	1885.	1886.	Average of Two Years.
January	32	38	35·0
February	44	39	41.5
March	37	49	43.0
April	37	38	37.5
May	51	58	54.5
June	46	30	38.0
July	32	36	34.0
August	30	46	38.0
September	45	41	43.0
October	41	33	37.0
November	47	22	34.5
December	40	42	41.0
Total	482	472	477.0
Monthly average.	40.2	39.3	39.75

As will be seen from the table, the total number for 1886 is 472, and the monthly average is 39·3. The number in February is almost equal to this average. Those in March, May, August, September, and December are above the average, while those in January, April, June, July, October, and November are below it. The two highest are in May and the lowest in November. The month of the highest number is the same in the two years, but that of the lowest number is different.

If we divide this number of earthquakes into four seasons, we have :—

	1885.	1886.	Average of Two Years.
Spring (3-5)	125	145	135.0
Summer (6-8)	108	112	110.0
Autumn (9-11)	133	96	114.5
Winter (12-2)	116	119	117.5
Total	482	472	477.0
Average	120.5	118.0	119.25

As in the list, the average number of earthquakes in a season was 118, and those in spring and winter were above the average while those in summer and autumn have been below it. The highest was in spring and the lowest in autumn. In many respects this is different from the observations of the last year.

Dividing the same observations into warm and cold seasons, we have :—

	1885.	1886.	Means.
Winter (10-3)	241	223	232
Summer (4-9)	241	249	245
Total	482	472	477
Average	241.0	236.0	238.5

We see from the list that the mean of a season is 236 for 1885, and the number in summer months is greater than the mean while in winter months it is less. The difference between the two seasons is 26. In 1885 the number was eqaul in the two seasons.

N.B.—The number of earthquakes for 1885 in this report is different from those which were given already in the report of last year. This difference results from the addition of

reports received later and corrections of errors in the former report. The numbers in this report may be taken as correct.

TIME OF OCCURRENCE OF EARTHQUAKES.

The following table shows the number of earthquakes for 1885 and 1886 which occurred at different hours of the day:—

TIME A.M.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	TOTAL
0—1	0	4	2	3	2	6	4	3	0	1	4	4	33
1—2	2	7	3	0	2	6	3	0	4	6	2	1	36
2—3	4	3	7	5	8	4	5	11	11	1	3	3	65
3—4	4	4	3	4	10	0	4	3	5	3	4	4	48
4—5	1	4	0	3	6	4	1	2	3	1	1	1	27
5—6	2	1	7	2	10	0	4	4	1	6	3	0	40
6—7	4	2	2	3	4	1	4	2	4	2	1	5	34
7—8	3	1	3	6	3	3	1	1	1	3	5	3	33
8—9	4	3	5	4	4	2	4	3	8	1	1	2	40
9—10	4	4	3	5	2	8	2	2	3	4	1	1	39
10—11	6	0	2	4	0	2	1	1	2	2	2	3	25
11—12	2	3	3	4	6	4	4	2	4	3	3	6	44
P.M.													
0—1	2	2	1	1	3	1	3	2	6	3	2	2	28
1—2	2	4	4	3	10	3	2	3	4	6	5	3	49
2—3	6	2	9	3	5	3	6	4	3	3	3	4	51
3—4	1	3	1	5	4	1	2	5	4	2	2	3	33
4—5	2	2	6	2	5	3	2	2	1	1	1	2	29
5—6	3	8	3	2	3	5	2	0	2	0	0	1	29
6—7	2	2	3	3	4	3	3	3	6	4	2	4	39
7—8	3	5	2	4	2	3	3	4	2	5	3	3	39
8—9	1	2	3	4	6	2	4	4	4	5	8	7	50
9—10	2	2	4	1	5	3	2	4	6	3	5	6	43
10—11	6	9	7	2	3	5	1	4	0	6	4	9	56
11—12	5	6	3	2	2	4	1	7	2	3	4	5	44
Total	70	83	86	75	109	76	68	76	86	74	69	82	954

Mean number per hour=40.

Thus we see from the table that the number of shakings at 6 and 9 a.m. is equal to the mean number or 40. Those above the mean are at 3 and 4 a.m., noon, 2, 3, 9, 10, 11, p.m., and midnight. Those below the mean are at 1, 2, 5, 7, 8, 10, 11, a.m., 1, 4, 5, 6, 7, 8, p.m. Those hours having numbers below the mean are more than those above it by 4. The maximum was at 3 a.m., and the minimum at 11 a.m. The same number of 44 is at noon and midnight, and 40 at 6 and 9 a.m. 39 at 10 a.m., 7, 4, 8, p.m. 33 at 8 a.m. and 4 p.m. In short, there were many more earthquakes at p.m. than at a.m.; the difference being 26. Although at noon and midnight the

earthquakes were equal in number, yet 11 a.m. was the least of all while 11 p.m. was the highest but one. When we compare the number of earthquakes by day and by night, taking 6 o'clock as the limit of day and night, there were 86 more earthquakes in the latter than in the former.

How the occurrence of earthquakes are related to day and night or the hours of the day, we cannot say definitely.

AREA OF SEISMIC DISTURBANCES.

Although some seismic disturbances are of only small extent, yet there have been others extending over several thousand square *ri*, as mentioned in the report of the last year. In the following table the number of square *ri* shaken every month in 1886 together with the area shaken in the previous year is given :—

	TOTAL AREA.			MEAN AREA PER SHOCK.		
	1885. Square *ri*.	1886. Square *ri*.	AVERAGE. Square *ri*.	1885. Square *ri*.	1886. Square *ri*.	AVERAGE. Sq. *ri*.
Jan.	10,020 ...	3,240 ...	6,630 ...	370 ...	80 ...	195
Feb.	16,980 ...	5,550 ...	11,265 ...	390 ...	140 ...	265
March......	7,320 ...	4,810 ...	6,065 ...	200 ...	100 ...	150
April	4,750 ...	12,480 ...	8,615 ...	130 ...	330 ...	230
May	10,380 ...	15,380 ...	12,880 ...	200 ...	260 ...	230
June	15,890 ...	5,080 ...	10,485 ...	370 ...	170 ...	270
July.........	.9,170 ...	10,490 ...	9,830 ...	290 ...	290 ...	290
Aug.	6,060 ...	10,820 ...	8,440 ...	210 ...	230 ...	220
Sept.	4,570 ...	9,500 ...	12,035 ...	320 ...	230 ...	275
Oct..........	21,340 ...	3,860 ...	12,600 ...	520 ...	120 ...	320
Nov.........	4,120 ...	2,480 ...	3,300 ...	80 ...	110 ...	90
Dec.	1,170 ...	8,360 ...	10,030 ...	290 ...	200 ...	245
Total......	132,300 ...	92,050 ...	112,175 ...	2,310 ...	2,260 ...	2,785
Average..	11,025 ...	7,671 ...	9,348 ...	276 ...	189 ...	232

Thus the total of the area shaken in 1886 was 92,050 square *ri*, which gave the monthly mean of 7,671 sq. *ri* or 189 sq. *ri* per shock. In the same year there were 66 earthquakes which exceeded the mean value of 189 sq. *ri*. Compared with the last year, there were 40,250 sq. *ri* less area shaken, 3,350 sq. *ri* less in the monthly mean, 87 sq. *ri* less the mean area per shock, and 30 earthquakes less which exceeded the mean value.

N.B.—The total area shaken this year was 92,050 sq. *ri* which is 3.8 times larger than the total area of this country or 24,352 sq. *ri* (exclusive of many small islands and Loochoo).

The following table shows the number of earthquakes shaking different area in different months during 1885 and 1886 :—

Area.	Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	Mean.
More than 5,000 square *ri*	1886	—	—	—	—	—	—	1	—	—	—	—	—	1	0.1
More than 5,000 square *ri*	1885	—	1	—	—	—	—	—	—	—	1	—	—	2	0.2
More than 4,000 square *ri*	1886	—	—	—	1	—	—	—	—	—	—	—	—	1	0.1
More than 4,000 square *ri*	1885	—	—	—	—	—	—	—	—	—	—	—	—	—	—
More than 3,000 square *ri*	1886	—	—	—	—	1	—	1	1	—	—	—	—	3	0.3
More than 3,000 square *ri*	1885	—	—	1	—	1	1	1	—	1	1	—	—	6	0.5
More than 2,000 square *ri*	1886	—	—	—	1	2	—	—	1	1	—	—	—	5	0.4
More than 2,000 square *ri*	1885	1	2	—	—	1	2	1	—	3	1	—	2	13	1.1
More than 1,000 square *ri*	1886	—	1	—	1	1	1	—	—	3	—	1	1	9	0.8
More than 1,000 square *ri*	1885	—	1	—	1	—	1	—	1	—	4	—	1	9	0.8
Sum	1886	—	1	—	3	4	1	2	2	4	—	1	1	19	1.6
Sum	1885	1	4	1	1	2	4	2	1	4	7	—	3	30	2.5
Comparison of 1886 and 1885.		* 1	* 3	* 1	† 2	† 2	* 3	—	† 1	—	* 7	† 1	* 2	* 11	* 0.9
More than 750 square *ri*	1886	—	1	2	1	2	1	—	2	—	1	—	2	12	1.0
More than 750 square *ri*	1885	2	1	1	—	—	2	1	1	2	—	—	2	12	1.0
More than 500 square *ri*	1886	1	1	—	2	—	—	—	1	2	2	—	4	13	1.1
More than 500 square *ri*	1885	5	4	1	1	—	1	—	2	1	2	—	—	17	1.4
More than 300 square *ri*	1886	2	2	2	1	3	4	1	1	—	2	1	1	20	1.7
More than 300 square *ri*	1885	2	1	—	2	4	1	2	1	—	6	1	4	24	2.0
More than 200 square *ri*	1886	2	—	4	1	4	2	2	2	1	—	—	2	20	1.7
More than 200 square *ri*	1885	—	1	2	1	1	4	—	4	1	2	9	2	27	2.2
More than 100 square *ri*	1886	5	3	2	3	4	4	1	5	4	3	1	4	39	3.2
More than 100 square *ri*	1885	3	6	5	6	16	7	4	2	4	—	5	5	63	5.2
Sum	1886	10	7	10	8	13	11	4	11	7	8	2	13	104	8.7
Sum	1885	12	13	9	10	21	15	7	10	8	10	15	13	143	11.9
Comparison of 1886 and 1885.		* 2	* 6	† 1	* 2	* 8	* 4	* 3	† 1	* 1	* 2	* 13	0	* 39	* 3.2
Less than 100 square *ri*	1886	28	31	39	27	41	18*	30	33	30	25	19	28	349	29.1
Less than 100 square *ri*	1885	19	27	27	26	28	27	23	19	33	24	32	24	309	25.7
Sum	1886	28	31	39	27	41	18	30	33	30	25	19	28	349	29.1
Sum	1885	19	27	27	26	28	27	23	19	33	24	32	24	309	25.7
Comparison of 1886 and 1885.		† 9	† 4	† 12	† 1	† 13	* 9	† 7	† 14	* 3	† 1	* 13	† 4	† 40	† 3.3
Grand Total ...	1886	38	39	49	38	58	30	36	46	41	33	22	42	472	39.3
Grand Total ...	1885	32	44	37	37	51	46	32	30	45	41	47	40	482	40.2
Comparison of 1886 and 1885.		† 6	* 5	† 12	† 1	† 7	* 16	† 4	† 16	* 4	* 8	* 25	† 2	* 10	* 0.8

* = —. † = +.

It will be seen from the above table that out of all the earthquakes which occurred during 1886, 349 shocks were local, shaking less than 100 square *ri*, 104 shocks extended over more than 100 square *ri*, and 19 had wider extension than 1,000 square *ri*. Of the latter only one extended more than 5,000 square *ri*.

In comparing these observations with those of last year, we see that of earthquakes having an area less than 100 square *ri*, there were 40 more in this year; of those shaking more than 100 square *ri* there were 29 less, and of those wider than 1,000 square *ri* there were twice less. In general we must say that in 1886 there were many earthquakes of a local nature and comparatively few which shook a large area.

Distribution of Seismic Disturbances.

We have already stated in our last report that the districts subject to seismic disturbances are not constantly fixed.

There were considerable changes observed in Echigo, Shinano, Mutsu, Kai, and Kadzusa, while all other parts were not materially different from what we had in 1885, although there were some differences in the number of shocks observed.

The districts most frequently affected by earthquakes in this year were Shimotsuke, Musashi, Hitachi, and Shimosa. Next follow Nemuro and Kushiro, after which come Echigo, Iwaki, Shinano and Mutsu.

As to Shimotsuke, Musashi, Shimosa, and Hitachi no great differences were observed as compared with last year. Fifty-five shocks were reported. The same was the case with Nemuro and Kushiro where they had 20 and 40 shocks. The same was the case in Kii.

In Echigo and Shinano the number of earthquakes in this year was much increased; in 1885 there were 3 earthquakes in Echigo and 9 in Shinano, while in 1886 there were 31 in the former and 19 in the latter. On the contrary, we had a decrease in the number in Mutsu, Kadzusa, and Kai. The increase in the num-

ber of earthquakes in Echigo and Shinano was due to the strong shocks which occurred on July 23rd and several small ones which followed them. Yet we cannot decide from these facts that those districts are seismic regions, which now and then experience severe shakings. Mutsu, Kadzusa, and Kai, although they were less frequently disturbed this year than during the last, were shaken much more than the adjacent provinces. The continual succession of disturbances in these provinces leads us to think that they are truly seismic regions.

There were more than 10 earthquakes in Iyo and Satsuma, the former being more frequently disturbed and the latter less frequently than during last year. We are not certain that Iyo may be taken as a seismic region, but we may take Satsuma as such, for there it appears that earthquakes are always frequent.

As in the last report the number of earthquakes felt in each province is given in the following table :—

No. of Earthquakes of different intensity.

Name of Province.	Year.	Number of Earthquakes.	Strong.	Weak.	Feeble.
Shimotsuke	1886	61	1	5	55
	1885	58	1	18	39
Musashi	1886	54	1	15	38
	1885	68	2	18	48
Nemuro	1886	43	1	15	27
	1885	33	4	22	7
Hitachi	1886	33	1	23	28
	1885	36	0	8	9
Echigo	1886	31	3	7	21
	1885	3	1	1	1
Shimosa	1886	28	0	17	11
	1885	40	0	15	25
Kushiro	1886	23	4	13	6
	1885	15	1	8	6
Kii	1886	22	1	6	15
	1885	18	0	7	11
Iwaki	1886	19	0	16	3
	1885	19	1	13	5
Shinano	1886	19	2	14	3
	1885	9	0	5	4
Mutsu	1886	15	0	6	9
	1885	26	2	8	16
Kadzusa	1886	14	0	4	10
	1885	22	0	4	18

No. of Earthquakes of different intensity.

Name of Province.	Year.	Number of Earthquakes.	Strong.	Weak.	Feeble.
Rikuzen	1886	12	3	5	4
	1885	16	0	11	5
Kodzuke	1886	11	2	6	3
	1885	11	0	10	1
Kai	1886	11	2	4	5
	1885	21	6	6	9
Rikuchiu	1886	10	0	6	4
	1885	9	4	4	1
Iyo	1886	10	3	6	1
	1885	3	0	2	1
Satsuma	1886	10	0	6	4
	1885	10	1	4	5
Iwashiro	1886	9	0	6	3
	1885	5	0	3	2
Ugo	1886	8	2	2	4
	1885	3	0	3	0
Sagami	1886	8	1	3	4
	1885	15	1	13	1
Idzumo	1886	7	0	5	2
	1885	4	0	2	2
Mino	1886	6	0	4	2
	1885	13	3	8	2
Hiuga	1886	6	0	3	3
	1885	5	0	1	4
Bungo	1886	6	1	2	3
	1885	2	0	2	0
Iwami	1886	6	0	1	5
	1885	2	0	2	0
Chikuzen	1886	6	0	4	2
	1885	1	0	1	0
Aki	1886	5	0	1	4
	1885	5	0	2	3
Tosa	1886	5	2	3	0
	1885	3	1	2	0
Uzen	1886	5	1	3	1
	1885	7	0	6	1
Ise	1886	5	0	3	2
	1885	7	0	3	4
Mikawa	1886	4	0	1	3
	1885	10	0	3	7
Hizen	1886	4	0	0	4
	1885	3	0	2	1
Tanba	1886	4	0	3	1
	1885	7	0	4	3
Owari	1886	3	0	2	1
	1885	8	0	2	6
Nagato	1886	3	0	2	1
	1885	5	0	3	2
Suwo	1886	3	0	3	0
	1885	5	0	1	4

No. of Earthquakes of different intensity.

Name of Province.	Year.	Number of Earthquakes.	Strong.	Weak.	Feeble.
Buzen	1886	3	1	1	1
	1885	1	0	1	0
Harima	1886	3	0	2	1
	1885	2	0	1	1
Settsu	1886	3	0	1	2
	1885	5	0	1	4
Ōsumi	1886	3	0	2	1
	1885	5	0	3	2
Oshima	1886	3	0	1	2
	1885	9	2	5	2
Echizen	1886	3	0	1	2
	1885	4	0	2	2
Noto	1886	3	1	2	0
	1885	—	—	—	—
Awa	1886	3	0	3	0
	1885	9	1	8	0
Kawachi	1886	3	1	1	1
	1885	2	0	2	0
Iga	1886	3	0	0	3
	1885	3	0	2	1
Totomi	1886	2	0	0	2
	1885	5	0	4	1
Etchiu	1886	2	0	0	2
	1885	—	—	—	—
Iburi	1886	2	0	1	1
	1885	7	1	4	2
Higo	1886	2	0	2	0
	1885	4	0	3	1
Suruga	1886	2	0	1	1
	1885	8	1	2	5
Awa	1886	2	0	2	0
	1885	7	0	2	5
Yamato	1886	2	0	2	0
	1885	5	0	4	1
Yamashiro	1886	2	0	0	2
	1885	5	0	4	1
Oumi	1886	2	0	0	2
	1885	6	0	1	5
Chishima	1886	2	1	0	1
	1885	6	2	1	3
Bizen	1886	2	0	0	2
	1885	1	0	0	1
Chikugo	1886	1	0	1	0
	1885	1	0	0	1
Ishikari	1886	1	1	0	0
	1885	4	1	2	1
Shiribeshi	1886	1	0	1	0
	1885	2	0	2	0
Idzumi	1886	1	0	1	0
	1885	2	0	1	1

No. of Earthquakes of different intensity.

Name of Province.	Year.	Number of Earthquakes.	Strong.	Weak.	Feeble.
Bitchiu	1886	1	0	0	1
	1885	2	0	0	2
Bingo	1886	1	0	0	1
	1885	1	0	0	1
Wakasa	1886	1	0	0	1
	1885	3	0	0	3
Sado	1886	1	0	1	0
	1885	—	—	—	—
Hida	1886	1	1	0	0
	1885	3	0	1	2
Tango	1886	1	0	1	0
	1885	1	0	0	1
Idzu	1886	1	1	0	0
	1885	5	2	2	1
Awaji	1886	1	0	1	0
	1885	2	0	1	1
Iki	1886	1	0	0	1
	1885	—	—	—	—
Shima	1886	—	—	—	—
	1885	4	0	2	2
Hidaka	1886	—	—	—	—
	1885	3	1	2	0
Hoki	1886	—	—	—	—
	1885	2	0	2	0
Teshio	1886	—	—	—	—
	1885	2	1	1	0
Mimasaku	1886	—	—	—	—
	1885	1	0	1	0
Total	1886	596	38	253	305
	1885	659	40	294	325

Intensity of Earthquakes.

As we have stated in the report of last year, the intensity of earthquakes was quite variable. The provinces which felt strong earthquakes were Kushiro and Rikuzen, where there were 6 strong shocks; next come Musashi, Iyo, Hitachi, Echigo, Shinano, Iwaki, Shimotsuke, each of which felt 3 to 5 shocks. Nemuro, Ugo, Iwashiro, Shimosa, Kodzuke, Kai, Tosa, Chishima, Mutsu, Rikuchiu, Uzen, Noto, Sagami, Idzu, Hida, Owari, Kawachi, Kii, Suwo, Buzen, Bungo, and Hizen had 1 or 2 strong shocks. Above all, the strongest earthquake was one which occurred on the 23rd of July in the provinces of Echigo and Shinano, where more or less damage was done.

(See plate III., map 3, and also the special record of that earthquake further on.)

Positions of Seismic Origins.

To know the exact positions of earthquake origins is rather a hard task, but a few remarks may be made as to their approximate positions.

The 472 shocks which were felt during this year have been grouped according to their approximate origins, which are indicated by small circles in Plate II. The figures enclosed within the circles mean that the spots so indicated were so many times approximately the origins of earthquakes. For instance 72 written within a circle means that within that circle 72 shocks originated. We are not, however, in a position to firmly assert that all the shocks of which we speak have necessarily originated within the spaces enclosed by circles.

There may be many shocks which came from origins more than 10 *ri* outside of a circle, especially perhaps those which had their origins under the sea.

In this year, the seismic origins in the mainland were at its central part, or between Tokaidō and Hokurokudō. Those in Hokkaidō were under the sea to the east, while in the western part they were near the coast.

Thus seismic origins were either inland, on the coasts or under the sea.

There were 228 shocks which may be traced to origins on the coast or under the sea, and they were usually extensive in their effect, while those originating beneath the land were 244. These latter merely caused limited disturbances.

The seismic origins which caused the widest disturbances were stationed either under the sea off the coasts of Hokkaido, Mutsu, Rikuchiu, Rikuzen, Iwaki, and Hitachi, or on the coast itself. These earthquakes extended over an area of from 3,900 square *ri* to 5,700 square *ri*.

The origin which gave rise to the most numerous shocks

was within Shimotsuke, Musashi, and Hitachi, where there were 72 shakings. The next was in Echigo and Shinano, where there were 52 shocks. Yet of these earthquakes, no one extended over more than 550 square *ri*. In comparing the intensity of earthquakes, there were 23 strong shocks which originated under the sea or on the coast and 19 strong shocks on the land.

Besides these there were several other important seismic origins which are inserted in Plate II. The following will show the number of shocks coming from different origins:—

	From origins under the sea or on the coast.	From origins beneath the land.	Total number.
Disturbances extending over a wide area......	15	11	26
Disturbances extending over a limited area...	50	70	120
Disturbances extending over a small area......	163	163	326
Total	228	244	472

RELATION OF EARTHQUAKES TO VOLCANOES.

On enquiring into the relation of earthquakes to volcanoes we find that there were, as last year, many earthquakes felt in Musashi, Kazusa, Shimōsa, Kōdzuke, Shimotsuke, and Hitachi which are almost enclosed by ranges of volcanoes. There were, however, many earthquakes also in Kii, which is quite apart from any volcanoes. Among those provinces having volcanoes, Mutsu is in its northern parts the one most frequently shaken. There are also many provinces where there are volcanic peaks, but where no earthquakes have been felt. This is the same as last year, but a difference is that a severe earthquake causing considerable damage originated at the boundary of Echigo and Shinano where there is a range of volcanoes but where no earthquakes were felt during the last year. (See plate III. map 3 and the record for July 23rd.) After this earthquake there were several small ones, giving a total of 31 shocks for Shinano.

There are some volcanic districts which were comparatively free from earthquakes, while in other places where no volcano exists there have been felt quite a number of earthquakes; other places again are at once free from earthquakes and volcanoes; some districts quite close to a volcano were constantly shaken. These being the facts, we cannot hastily assent to a theory that attributes the frequency and intensity of earthquakes to the presence of volcanoes. The situation of volcanoes is indicated by ▲ or △ on the map of Plate I. The volcanoes marked ▲ are active ones which are sending out smoke at present or which are recorded to have been in eruption within historic times. Those marked △ are extinct volcanoes which are only inferable as such from geological reasons.

ON THE MONTHLY OCCURRENCE OF EARTHQUKES.

As the seismic conditions of this year as a whole have already been explained in the preceding pages, the following will be devoted to a description of the earthquakes which have occurred during successive months.

JANUARY.

The total number of earthquakes in this month was 38, which was at the rate of 1 shock every 19h. 34m.

The districts disturbed were Nemuro in Hokkaido, Mutsu, Rikuchiu, Rikuzen, Iwaki, Hitachi, Kadzusa, Shimōsa, Musashi, Shimotsuke, Shinano, Totomi, Mikawa, Kawachi, Yamato, Kii, Settsu, Idzumi, and Iwami on the mainland together with Satsuma in Kiushiu.

The province shaken most frequently was Kii, where there were 4 earthquakes; next came Musashi, Shimōsa, and Rikuzen each of which had 3 earthquakes, and all the rest 2 or less.

There were only 3 strong earthquakes felt in the 3 provinces of Kai, Totomi, and Rikuzen, all the others being weak or feeble earthquakes.

The total area of the districts disturbed was 3,240 square

ri. There were 10 earthquakes which disturbed more than 100 square *ri*, and no one extended over 1,000 square *ri.*

The one which caused the widest disturbance occurred on the 26th and extended from the central part of Rikuchiu to Iwaki, embracing Rikuzen, or an area over 630 square *ri.*

FEBRUARY.

The total number of earthquakes during this month was 39, which was at the rate of 1 shock every 17h. 39m.

The districts disturbed were Chishima, Nemuro, Kushiro, Ishikari, Iburi, and Shiribeshi in Hokkaido, Ugo, Rikuchiu, Rikuzen, Iwaki, Kodzuke, Shimotsuke, Hitachi, Kadzusa, Shimōsa, Musashi, Sagami, Kai, Shinano, Mino, Kii, Harima, Iwami, and Nagato on the mainland, Tosa and Iyo in Shikoku, together with Bungo, Hizen, Higo, and Satsuma, in Kiushu.

The province most frequently shaken was Nemuro, there being 5 shocks; next came Hitachi, Shimosa, and Shimotsuke which had each 4 shocks, and all the rest had 3 or less.

There were 4 strong earthquakes, which occurred in Shinano, Ishikari, Iyo, and Musashi. All the others were either weak or feeble earthquakes.

The total area of districts disturbed by earthquakes was 5,550 square ri. There were 7 earthquakes which disturbed more than 100 square ri. One which caused the widest disturbance was on the 24th. It extended over Kadzusa, Sagami, Kai, Kodzuke, Shimotsuke and Hitachi, or an area of 1,740 square *ri.*

MARCH.

The total number of earthquakes which occurred during this month was 49, which was at the rate of 1 shock in every 15h. 11m.

The districts shaken were Nemuro and Kushiro in Hokkaido, Mutsu, Rikuzen, Uzen, Iwashiro, Iwaki, Hitachi, Kadzusa, Shimōsa, Awa, Musashi, Shimotsuke, Echigo, Suruga, Mikawa, Mino, Owari, Ise, Omi, Echizen, Tamba, Settsu, Kawachi, Yamato, Idzumi, Kii, Harima, and Idzumo

on the mainland, Awa in Shikoku, and Hizen and Satsuma in Kiushiu.

The provinces most frequently shaken were Nemuro, Kushiro, Mutsu, and Kii, which had each 4 earthquakes. Next came Shimotsuke, Shimōsa, and Musashi, which had each 3, and all the rest had 2 or less.

There were 4 strong earthquakes, occurring in Rikuzen, Iwashiro, Kawachi, and Kushiro. All the other earthquakes were feeble.

The total area of the districts disturbed was 4,810 square *ri*, there being 10 earthquakes which extended over more than 100 square *ri*. The largest disturbance occurred on the 2nd, and extended over a region having Iwaki and Shimotsuke as the northern limit and Musashi and Awa as the southern limit, and an area of 790 square *ri*.

APRIL.

The total number of earthquakes in April was 38, so that there was on the average 1 shock every 18h. 56m.

The districts disturbed were Nemuro and Kushiro in Hokkaido, Mutsu, Rikuchiu, Rikuzen, Uzen, Ugo, Iwashiro, Iwaki, Hitachi, Kadzusa, Shimōsa, Musashi, Kodzuke, Shimotsuke, Echigo, Shinano, Noto, Echizen, Ise, Owari, Mikawa, Totomi, Kii, Yamashiro, Wakasa, Tanba, Iwami, Aki, and Suwo on the mainland, Iyo and Tosa in Shikoku, Bungo, Hiuga, and Hizen in Kiushiu.

The provinces most frequently shaken were Iwaki, Shimotsuke, and Rikuzen, each having 4 earthquakes. Next came Hitachi, Shimōsa, Iwashiro, Mutsu, and Nemuro, each having 3. All the others had two or less.

There were 7 strong earthquakes, of which 5 were felt in Ugo, Kushiro, Shimotsuke, Mutsu, and Iyo; of the two others one extended over Rikuzen, Rikuchiu, Ugo, Uzen, and Iwaki, and the other over Echigo and Kodzuke. All the rest were feeble.

The total area of ground which was shaken was 12,480 square *ri*. There were 7 earthquakes which extended over more than 100 square *ri*, and 3 over more than 1,000 square *ri*. The largest, on the 13th, extended over Mutsu and Ugo in the north-east and Musashi and Shimōsa in the south, or over an area of 4,980 square *ri*.

MAY.

The total number of earthquakes felt during this month was 58, which is an average of 1 shock for every 12h. 49m.

The districts disturbed were Chishima, Nemuro, Kushiro, and Oshima in Hokkaido, Mutsu, Rikuchiu, Rikuzen, Ugo, Iwashiro, Iwaki, Kadzusa, Shimōsa, Kodzuke, Shimotsuke, Awa, Musashi, Sagami, Hitachi, Kai, Idzu, Echigo, Shinano, Suruga, Mino, Owari, Echizen, Iga, Settsu, Yamashiro, Yamato, Kawachi, Idzumi, Kii, Harima, Tanba, Aki, Suwo on the mainland, Iyo in Shikoku, Awaji (island), Buzen, Chikuzen, Iki, Hizen, and Chikugo in Kiushiu.

The provinces most frequently disturbed were Shimotsuke, Hitachi, Shimōsa, and Musashi. Here there were from 8 to 11 earthquakes. Next came Kai, Chikuzen, Iwashiro, Kii, Kodzuke, Iwaki, Kushiro, Mutsu, Buzen, and Nemuro which had from 3 to 5 earthquakes. All the other provinces had only 2 or less.

There were 8 strong shocks, 4 of which occurred in the provinces Kii, Nemuro, Chishima, and Hitachi. Of the 4 others, one extended over Shimōsa, Musashi, Shinano, Kai, Sagami, and Idzu, another over Buzen, Chikuzen, and Hizen the third over Hitachi, Shimōsa, Musashi, Kozuke, Shimotsuke, and Iwaki, and the last in Rikuzen. All the rest were feeble.

The area of the districts disturbed was 15,380 square *ri*; 13 earthquakes extended over more than 100 square *ri* and 4 over more than 1,000 square *ri*. The largest disturbance occurred on the 16th, and extended over Hitachi, Kozuke, Shimotsuke, Kadzusa, Shimōsa, Awa, Musashi, Sagami, Kai,

Shinano, Echigo, Iwaki, Iwashiro, and Rikuzen, or an area of 3,110 square *ri*.

JUNE.

The total number of earthquakes felt during this month was 30, or an average of 1 shock every 24 hours.

The districts disturbed were Nemuro and Kushiro in Hokkaido, Mutsu, Rikuzen, Iwaki, Hitachi, Kadzusa, Shimōsa, Shimotsuke, Musaki, Sagami, Shinano, Kii, Bizen, Idzumo, Iwami, and Aki on the mainland, Awa, Iyo, and Tosa in Shikoku, Buzen, Bungo, and Hiuga in Kiushiu.

The provinces most frequently shaken were Musashi, Kushiro, and Iyo, each having 4 earthquakes. Then come Hitachi, Shimotsuke, Nemuro, and Aki, each of which had 3 shocks, all the rest having not more than two.

There were 5 strong earthquakes; two in Iyo, one in Nemuro and Kushiro, one in Tosa and one in Hitachi. All the other shocks were feeble.

Only one shock disturbed more than 1,000 square *ri*. The one which caused the widest disturbance was on the 3rd. It extended over Musashi, Kadzusa, Hitachi, Iwaki, and Shimotsuke, or over an area of 1,010 square *ri*.

JULY.

The total number of earthquakes in this month was 36, that is on the average one shock every 20h. 40m.

The provinces disturbed were Nemuro, Kushiro, and Oshima in Hokkaido, Mutsu, Rikuchiu, Rikuzen, Ugo, Uzen, Iwashiro, Iwaki, Hitachi, Kodzuke, Shimotsuke, Shimōsa, Musashi, Kai, Shinano, Echigo, Noto, Sado, Etchiu, Mino, and Bingo on the mainland, Hiuga, Osumi, and Satsuma in Kiushiu.

The province most frequently shaken was Echigo, where there were 16 shocks. Next came Shinano, which had 8. All the others had two or less.

There were 4 strong earthquakes, of which two occurred

in Kiushiu, one in Rikuzen, and one in Echigo, Shinano, and Noto. All the other shocks were feeble.

The total area disturbed was 10,490 square *ri*; 4 shocks affected more than 100 square *ri*, and 2 more than 1,000 square *ri*. The one which caused the widest disturbance was on the 2nd; it extended from Mutsu in the north to Kodzuke, Musashi, and Shimōsa in the south, or over an area of 5,580 square *ri*.

AUGUST.

The total number of earthquakes during this month was 46, that is there was an average of 1 shock every 16h. 14m.

The provinces disturbed were Nemuro, Kushiro, and Ōshima in Hokkaido, Mutsu, Rikuchiu, Rikuzen, Echigo, Kodzuke, Shimotsuke, Hitachi, Kadzusa, Shimōsa, Musashi, Shinano, Mino, Etchiu, Noto, Hida, Iga, Ise, Kii, Tanba, Tango, Bizen, Bitchiu, Aki, Suwo, Nagato, Iwami, and Idzumo on the mainland and all over Shikoku and Kiushiu, except Ōsumi in the latter.

The province most frequently shaken was Echigo, where there were 12 shocks. Next come Musashi, Shimotsuke, Shinano, Hitachi, Nemuro, and Mutsu, each having 8 to 3 shocks. All the other provinces had only 2 or less.

A strong earthquake was felt in Shinano and Echigo, another in Iyo, Tosa, Bungo, and Suwo, one in Echigo, one in Hida, and one in Kushiro, making up 5 in all. All the others were feeble.

The total area affected by earthquakes was 10,820 square *ri*. 11 earthquakes extended over more than 100 square *ri*, and 2 over more than 1,000 square *ri*. The one which caused the widest disturbance was on the 10th, extending over Shikoku, Kiushiu, and the western parts of the mainland, or over an area of 3,440 square *ri*.

SEPTEMBER.

The total number of earthquakes during this month was 41, which gives an average of 1 shock every 17h. 33m.

The provinces affected by earthquakes were Nemuro and Kushiro in Hokkaido, Mutsu, Rikuzen, Rikuchiu, Uzen, Iwaki, Iwashiro, Hitachi, Kadzusa, Shimosa, Musashi, Kodzuke, Shimotsuke, Kai, Sagami, Shinano, Echigo, Mino, Kii, Tanba, Idzumo, Aki, Iwami, and Nagato on the mainland, Tosa and Iyo in Shikoku, Bungo, Satsuma, and Ōsumi in Kiushiu.

The province most frequently disturbed was Shimotsuke, where there were 9 shocks. Next come Musashi, Echigo, Hitachi, Nemuro, Shimosa, and Iwaki, each experiencing 3 to 7 shocks; all the rest having not more than 2 disturbances.

There was only one strong earthquake, which occurred in Musashi; all the others were feeble.

The total area disturbed was 9,500 square *ri*; 7 earthquakes extended over more than 100 square *ri*, 4 over more than 1,000 square *ri*. The one which caused the widest disturbance was on the 21st. It extended over an area of 2,285 square *ri*, from Uzen and Rikuzen in the north to Kadzusa and Musashi in the south.

OCTOBER.

The total number of earthquakes which occurred during this month was 33, which gives an average of 1 shock every 22h. 32m.

The districts disturbed were Nemuro in Hokkaido, Iwaki, Hitachi, Kadzusa, Shimōsa, Musashi, Kodzuke, Echigo, Yamashiro, Kawachi, Kii, and Harima on the mainland, Tosa in Shikoku, Bungo, Hiuga, Ōsumi, and Satsuma in Kiushiu.

The province most frequently shaken was Shimotsuke, where there were 8 shocks. Then come Nemuro, Shimōsa, Musashi, Kii, and Echigo, which had from 3 to 5 shocks, all the other provinces having only 2 or less.

There were no strong earthquakes, all being feeble.

The total area shaken was 3,860 square *ri*; 8 shocks extended over more than 100 square *ri*, but none exceeded 1,000 square

ri. The largest was on the 18th, extending over Satsuma, Ōsumi, Hiuga, and Bungo, or over an area of 820 square *ri.*

NOVEMBER.

The total number of earthquakes during this month was 22, which gives an average of 1 shock every 32h. 48m.

The provinces disturbed were Nemuro and Oshima in Hokkaidō, Mutsu, Rikuzen, Iwaki, Iwashiro, Hitachi, Kōdzuke, Shimotsuke, Kadzusa, Shimōsa, Musashi, Sagami, Echigo, Mino, Owari, Mikawa, Ise, Kii, Tanba, and Idzumo on the mainland. No earthquakes were felt in Shikoku and Kiushiu.

The provinces most frequently shaken were Shimotsuke and Hitachi, each having 3 shocks. All the others had 2 or less.

All the disturbances were feeble.

The total area of districts disturbed was 2,480 square *ri;* 2 shocks extended over 100 square *ri*, and there was only one exceeding 1,000 square *ri.* The largest was on the 22nd, extending over Musashi, Kadzusa, Hitachi, Shimotsuke, Iwaki, Iwashiro, and Rikuzen, or over an area of 1,600 square *ri.*

DECEMBER.

The total number of earthquakes during this month was 44, which gives an average of 1 shock every 17h. 42m.

The provinces disturbed were Nemuro, Kushiro, and Iburi in Hokkaido, Ugo, Uzen, Mutsu, Rikuchiu, Rikuzen, Iwashiro, Iwaki, Hitachi, Kadzusa, Shimōsa, Musashi, Kodzuke, Shimotsuke, Sagami, Kai, Echigo, Mikawa, Owari, Ise, Mino, Idzumo, and Iwami on the mainland, Iyo, and Tosa in Shikoku. Nothing was reported from Kiushiu.

The provinces most frequently shaken were Musashi, Shimotsuke, and Nemuro, each having 6 to 8. Then come Hitachi, Iwaki, Rikuzen, Mutsu, Iwami, and Shimosa, which had 3 or 4 shocks. All the rest were shaken not more than twice.

There were 4 strong earthquakes, 1 in Rikuzen, 1 in Hitachi, Iwaki, Iwashiro, and Shimotsuke, 1 in Owari and 1 in Musashi. All the others were feeble.

The total area disturbed was 8,360 square *ri*. There were 13 earthquakes which extended over more than 100 square *ri*, and only one over more than 1,000 square *ri*. The largest was on the 4th, and it extended over Iwaki, Hitachi, Shimosa, Kadzusa, Musashi, Kodzuke, Shimotsuke, Iwashiro, and Rikuzen, or over an area of 2,220 square *ri*.

EXAMPLES OF EARTHQUAKES WHICH HAVE BEEN LARGE OR IN SOME WAY PECULIAR.

The following is a short account of the most remarkable earthquakes and of those districts which were frequently disturbed during 1886. In stating the time of shocks only the hours of their beginning are noted. In very extensive earthquakes there will, of course, be some differences in the exact time of commencement at different places.

JANUARY 24TH, 9.30 A.M. (No. 1, Plate III.)

A faint vibration was felt at the eastern extremity of Nemuro, and its area was not more than 10 square *ri*. In this small region the number of earthquakes which occurred this year was 28.

APRIL 13TH, 5.50 A.M. (No. 2, Plate III.)

This earthquake extended over the following 12 provinces, viz., Mutsu, Rikuchu, Ugo, Rikuzen, Uzen, Iwashiro, Iwaki, Kozuke, Shimozuke, Hitachi, Shimōsa, and Musashi. It was severe towards the south from the centre of Rikuchu, and all over Rikuzen; being most violent at Motoyoshi-gun along the eastern coast of Rikuzen; feeble in northern Rikuchu, Ugo, Uzen, Iwaki, and eastern Hitachi; and faint in eastern Iwashiro, more than half of Mutsu, eastern Kozuke, Shimodzuke, the western part of Hitachi, Shimōsa, and the eastern part of Musashi. Its area was 4,980 square *ri*. Its direction was not uniform, but in Motoyoshi-gun, in Rikuzen, and Nishi-hei-gun (西閉伊郡) in Rikuchu, where it was very severe, the direction was south-west and north-east. The nature of the shock was vertical in eastern Rikuzen and horizontal in other quarters. Perhaps the origin of this earth-

quake was in the Pacific, and from there it spread over the land. In Motoyoshi-gun in Rikuzen, and in Nishi-hei-gun in Rikuchu, at its beginning, there was a noise underground, and then suddenly a very violent vibration, everything on shelves being about to upset and fall down. It continued about three minutes. At Iku-gun (伊具郡), Iwaki, some liquid in a vessel was spilt. The earthquakes of Rikuzen, Rikuchiu, and Mutsu are very seldom propagated to Ugo beyond its eastern mountain ranges, but, at this time, the whole of the latter province experienced a feeble vibration. The shock was very severe in Akita, and it perhaps may have reached the Japan Sea. At about dawn of the same day there was an eruption of Mount Tarumai, in Iburi, Hokkaido; and at Nemuro there was felt a very feeble shock. Now, how such extraordinary events occurred at just the same time in the north-eastern part of this country is unknown, but they might owe their cause to considerable changes taking place in the earth-strata or the like.

JULY 23RD, 1 A.M. (No. 3, PLATE III.)

This earthquake extended over eleven provinces, viz., Echigo, Shinano, Etchu, Noto, Musashi, Kozuke, Shimozuke, Iwashiro, Sado, Shimōsa, and Hitachi. It was strong in half the places along the north coast from the centre of Echigo, being strong in more than $\frac{2}{10}$ of north-eastern Shinano, and in $\frac{3}{10}$ of northern Noto. The shock was most violent in more than $\frac{1}{10}$ of the north-eastern corner of Shinano, and in $\frac{1}{10}$ of southern Echigo; it was weak or faint in $\frac{3}{10}$ of the eastern, and $\frac{2}{10}$ of the western parts of Echigo, in Sado (?) it was felt in $\frac{6}{10}$ of western Iwashiro (?), in Kozuke, in Shimozuke, in $\frac{9}{10}$ of northern Musashi, in $\frac{2}{10}$ of north-western Shimōsa, in a small part of western Hitachi, in more than $\frac{3}{10}$ of central Shinano, in $\frac{8}{10}$ of eastern Echigo, and in $\frac{7}{10}$ of southern Noto. The area of the strong disturbance was 470 square *ri*, and that of the weak 2,520 square *ri*, making a total of 2,990 square *ri*. This was the most violent shock since the 17th year of Meiji. After

this time there were shocks at Higashi-kubiki-gun, in Echigo, up till 6 a.m. there were 4 weak and 19 faint shocks; clock pendulums stopped and furniture was upset. At Nigami-mura (*mura*=village) (仁上村) four store-houses were damaged; one stone wall 9 *shaku* high and 2 *ken* long, and another 7 *shaku* high and more than 7 *ken* long were destroyed. One *se* (1,080 square feet) of rice-fields at the same village, a part commonly called Hirakura Yama-shiri-da (平倉山尻田), and a bridge more than 15 *ken* long across the Hōkuragawa (*gawa*=river) (保倉川) from Ushi-ga-hana-mura, in the same *gun*, were destroyed. Besides this roads were damaged. The shock was so severe that many people in these districts fled out of doors. At Shimo-Takai-gun, in Shinano, though no cloud was seen that night, yet the moon was not clear and the weather was very hot since the day before; at Toyosato-mura (豊里村), in the same *gun*, one of the Nozawa hot springs (named Kiri-no-yu) was stopped by this earthquake. Around Teru-oka-mura (照岡村), in Shimo-minachi-gun (水内村), Shinano, several stone walls were destroyed; the cliffs of mountains, and roads, were broken down and the walls of many store-houses cracked; one house was upset and another tilted and partly destroyed; one store-house was upset and two others tilted; besides this much damage was done to lamp-shops, drug-shops, porcelain-shops, and the like. It was reported that, in the same *gun*, there were ten more very weak vibrations after the first one; at Kami-minachi-gun, the first shock was strong, causing some of the people to run out of doors, and this was followed by another shock. At Naka-Kubiki-gun, Echigo, though not very strong, there were five or six vibrations up till 4 o'clock the next morning; at Naka-Nonuma-gun, four shocks were felt, and crows and snowy herons in their roosts screamed, and some persons fled out of doors; at Mishima-gun, there were three shocks, and at Nishi-Kubiki and Kariha-gun two each. At Kita-Unuma-gun, there were five weak disturbances, and a few people fled out of doors. In each of Koshi-gun (古志郡)

and Minami-Uonuma-gun, in Echigo, and at Azuma-gun, Kōzuke, there were two mild shocks; at Kami and Shimo Takai-gun, many shocks were felt previous to this earthquake. After the 17th July, sometimes there were more than ten in a day.

It is probable that the origin of this earthquake was in the neighbourhood of Higashi-Kubiki, and of Takai-gun, for, in these two *gun*, the vibrations were very violent and numerous, while in Nishi-Kubiki and Naka-Kubiki-gun, they were evidently very weak.

At the same hour of the day (July 23rd, 1 a.m.), there was a weak vibration in eastern Mino, and its area was 50 square *ri*, but it seems that there was no connection between this part and those regions which we have mentioned above.

AUGUST 10TH, 9.30 P.M. (No. 4, Plate III.)

The earthquake of this day extended over Iyo, Bungo, Suwō, Aki, to the western part of Tosa, a small part of the south-west parts of Izumo, Iwami, Nagato, Buzen, Chikuzen, Chikugo, the eastern $\frac{4}{10}$ of Hizen, the north-eastern $\frac{8}{10}$ of Higo, the North-eastern $\frac{8}{10}$ of Hiuga, Bingo, Bitchu, the South-eastern $\frac{5}{10}$ of Bizen, the western $\frac{4}{10}$ of Awa, and to a small part of the south-west of Tanba. Its area was 3,440 square *ri*. It was strong in $\frac{8}{10}$ of the south-west of Iyo, in small part of the south-west of Tosa, in $\frac{3}{10}$ of the north-east of Bungo, and in $\frac{2}{10}$ of the south-west of Suwō. It was feeble in the other parts of Iyo and Tosa, in a small part of the south-west of Izumo, in Aki, Iwaki, Nagato, in the other parts of Suwō, in Buzen, in the other parts of Bungo, in $\frac{2}{10}$ of the northern end of Hiuga, in $\frac{3}{10}$ of the north-east of Higo, in Chikuzen, Chikugo, in $\frac{2}{10}$ of eastern Hizen. In all other places it was only faintly felt. The nature of the vibration was mostly horizontal, and it was said that in a part of the strong shocks, and in that of weak shocks close to the former, there were rumbling noises heard during its beginning. The probable origin of this earthquake seems to have been in Bungo Channel, and thence to have spread

out in all directions. Although many earthquakes have originated in the Bungo Channel, yet their vibrations have hitherto only spread along the neighbouring coasts, and scarcely ever inland. This was the only earthquake since the 17th year of Meiji that had so wide an extension. A few moments later there were two other shocks, the latter being somewhat stronger than the former.

Review of Earthquakes for 1884 and 1885.

The map in Plate IV. is constructed to show the total number of earthquakes during two years. From this we see that the districts most frequently shaken are Musashi, Shimōsa, Hitachi, and Shimotsuke. Tokyo and its neighbourhood have recorded 122. In the northern part of the main island, Mutsu experienced the greatest number (41). Nemuro stood highest in Hokkaido (76); Wakayama highest in the central part of the main island (40). In the districts of Sanindo and Sanyo-do, Aki, Suwō, Nagato, and Iwami had 7 or 8. Shikoku was most frequently shaken in its western part. Kagoshima and its neighbourhood stood highest (less than 18) in Kiushiu.

In general there were many more earthquakes in the north eastern part of Japan than in the western part, disturbances being most frequent in those parts of the country extending from Shimōsa to Mutsu. There were sometimes more than ten earthquakes in the central part of the main island, while in no region in the western part was this number reached excepting the cases mentioned above. We must here state that we had no report from the northern part of Hokkaido or from Kaga, Tajima, Inaba, the northern part of Hoki, and the eastern part of Idzumo.

The Report of Earthquakes recorded in Tokyo.

It is now eleven years since the systematic observation of earthquakes was commenced in Tokyo. This was in July, the 8th year of Meiji (1875). The number observed during these eleven years is more than 600. The results of the observations are given in the following tables. The 8th year of Meiji not being

complete, the list is commenced from the next year. During the seven years from the 9th to the 15th of Meiji (1876-1882), the observations were made at Aoicho, Akasaka, but after that date they were made at Honmaru, in the Castle. From the beginning to the 18th year of Meiji (1885), the observations were made by Palmieri's apparatus, but from the next year by the Gray-Milne Seismograph. One will at once notice that earthquakes in Tokyo have evidently been very much more frequent than they have been in other localities.

THE FREQUENCY OF EARTHQUAKES AND THE TIMES OF THEIR OCCURRENCES.

The following Table gives 658 earthquakes observed at the Imperial Meteorological Central Observatory during eleven years from the 9th to the 19th year of Meiji :—

YEARS. MEIJI	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL	AVERAGE
1876... 9th......	3	4	6	11	5	3	3	5	3	3	4	6	56	5
1877... 10th......	4	5	6	5	8	6	6	4	1	8	6	9	71	6
1878... 11th......	3	8	7	2	5	4	4	1	2	4	6	4	50	4
1879... 12th......	6	7	14	0	9	4	3	4	1	7	6	9	70	6
1880... 13th......	9	9	6	6	2	9	8	4	1	3	10	10	77	6
1881... 14th......	13	8	8	8	4	3	3	3	2	3	3	8	66	5
1882... 15th......	4	7	15	6	3	2	2	1	1	4	1	0	46	4
1883... 16th......	6	0	3	3	6	2	3	1	0	1	3	4	32	3
1884... 17th......	5	2	8	2	9	4	1	4	2	8	8	15	68	6
1885... 18th......	7	9	8	4	3	6	0	3	8	10	3	7	68	6
1886... 19th......	3	3	3	2	8	4	2	8	7	4	2	8	54	4
Total.........	63	62	84	49	62	50	35	38	28	55	52	80	658	54.8
Average	6	5	8	5	6	5	3	3	2	5	5	7	60	5

As shown in the Table, the average number of earthquakes in every year was 60. During six years, namely, the 10th, the 12th, the 13th, the 14th, the 17th, and the 18th year of Meiji, they were more than 60; but during five years, viz., the 9th, the 11th, the 15th, the 16th, and the 19th, less than 60. Of these, the largest number was in the 13th, and the least in the 16th year.

The average in every month was 5. So we have 5 in February,

April, June, October, and November; more than 5 in January March, May, and December; less than 5 in July, August, and September. There were most in March, and least in September.

THE NUMBER OF EARTHQUAKES DIVIDED INTO SEASONS.

YEARS.	MEIJI.	SPRING.	SUMMER.	AUTUMN.	WINTER.	AVERAGE.
1876	9th	22	11	10	13	14
1877	10th	19	19	15	18	18
1878	11th	14	9	12	15	25
1879	12th	23	11	14	22	17
1880	13th	14	21	14	28	19
1881	14th	20	9	8	29	16
1882	15th	24	5	6	11	11
1883	16th	12	6	4	10	8
1884	17th	19	9	18	22	17
1885	18th	15	9	21	23	17
1886	19th	13	14	13	14	13
Average		18	11	12	19	15

The average of every season was 15. There were more than 15 in spring and winter; less than 15 in summer and autumn; most in winter, and least in summer.

DIVIDED ACCORDING TO COLD (OCTOBER-MARCH) AND WARM (APRIL-SEPTEMBER) WEATHER.

YEARS.	MEIJI.	COLD.	WARM.	AVERAGE.
1876	9th	26	30	28
1877	10th	38	33	35
1878	11th	32	18	25
1879	12th	49	21	35
1880	13th	47	30	39
1881	14th	43	23	33
1882	15th	31	15	23
1883	16th	17	15	16
1884	17th	46	22	34
1885	18th	44	24	34
1886	19th	23	31	27
Average		36	24	30

The average of the two seasons was 30, there being more than 30 in the cold season.

THE HOURS OF EARTHQUAKES.

The 658 earthquakes mentioned in the first part of this Report are here divided according to the hours at which they occurred.

Hours. A.M.	A.M.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0 to	1	4	4	2	2	1	2	2	1	2	2	0	6	28
1 to	2	1	0	2	0	3	2	1	0	2	1	4	2	18
2 to	3	1	5	3	4	4	2	2	3	1	2	2	1	30
3 to	4	1	0	4	0	1	3	2	2	1	6	3	3	26
4 to	5	1	2	5	4	1	0	2	3	0	1	2	3	24
5 to	6	2	2	2	4	2	1	0	3	3	3	2	6	30
6 to	7	3	2	4	0	2	0	1	0	0	0	1	5	18
7 to	8	3	2	2	3	3	0	0	2	0	3	0	4	22
8 to	9	0	1	0	2	4	4	0	0	2	2	1	1	17
9 to	10	4	4	4	1	5	4	1	2	0	3	4	6	38
10 to	11	5	1	1	0	2	3	2	2	2	3	3	2	26
11 to	12	4	1	3	1	1	2	1	0	0	0	0	3	16
P.M.	P.M.													
0 to	1	2	1	2	1	4	6	3	0	2	0	4	4	29
1 to	2	3	4	4	3	1	2	2	1	2	6	2	2	32
2 to	3	2	4	4	1	0	1	2	3	0	0	0	3	20
3 to	4	3	5	3	3	4	2	3	0	2	0	6	0	31
4 to	5	3	1	9	3	0	3	2	3	2	1	2	3	32
5 to	6	2	3	2	2	8	2	1	1	1	1	1	2	26
6 to	7	3	2	5	2	2	5	0	2	0	2	1	2	27
7 to	8	4	3	4	2	0	0	0	2	0	3	2	3	23
8 to	9	3	4	4	3	2	0	3	3	3	8	6	8	47
9 to	10	3	2	4	4	5	1	2	2	1	2	3	3	32
10 to	11	3	4	5	3	2	2	1	2	1	3	0	6	32
11 to	12	3	5	6	1	5	3	2	1	1	2	3	2	34
Total		63	62	84	49	62	50	35	38	28	55	52	80	658

According to the Table, earthquakes are most frequent at 8-9 p.m., next at 9-10 a.m.; least at 11 a.m.-12, and next least at 8-9 a.m. The most frequent, and the second least frequent are in hours at p.m. and at a.m. The least occur at a.m., and the most at p.m., the respective percentages being 55 and 45.

The hours when earthquakes are most numerous in each month are as follows:—

January	10-11 a.m.	—	—	—	—
February	2-3 a.m.	3-4 p.m.	11-mid-night p.m.		—
March	4-5 p.m.	—	—	—	—
April	2-3 a.m.	4-5 a.m.	5-6 a.m.	9-10 p.m.	—
May	5-6 p.m.	—	—	—	—
June	0-1 p.m.	—	—	—	—
July	0-1 p.m.	3-4 p.m.	8-9 p.m.	—	—
August	2-3 a.m.	5-6 a.m.	2-3 p.m.	2-3 p.m.	8-9 p.m.
September......	5-6 a.m.	8-9 p.m.	—	—	—
October.........	8-9 p.m.	—	—	—	—
November......	3-4 p.m.	8-9 p.m.	—	—	—
December......	8-9 p.m.	—	—	—	—

The hours when earthquakes are most frequent in particular months seem to be very uncertain, but generally speaking disturbances are frequent at night, especially from 8-9 p.m. during the six months between July and December.

Intensity of Earthquakes.

Tokyo ranks first or second in the frequency of earthquakes in Japan, but fortunately there has not been any severe disturbance since the observations were first made. The dates of the severest earthquakes, and their intensity since the 19th year of Meiji, are given below. The intensity is indicated by Palmieri's scale of degrees:—

Years.	Meiji.	Months and Days.	Times of First Vibrations.	Degrees of Vibrations.
1876	9th	20th January	8.44.30 p.m.	21°
1877	10th	22nd July	4.49.17 p.m.	11°
1878	11th	23rd February	6.03.45 a.m.	19° 20′
1879	12th	3rd December	7.08.00 a.m.	18° 30′
1880	13th	22nd February	0.50.19 a.m.	78° (out-run the instrument.)
1881	14th	18th June	10.25.0 a.m.	8° 30′
1882	15th	11th March	7.54.50 p.m.	11° 20′
1883	16th	10th June	10.15.0 p.m.	18° 20′
1884	17th	15th October	4.21.54 a.m.	95° 10′ (out-run the instrument.)
1885	18th	20th March	1.01.13 p.m.	22°
1886	19th	8th May	10.14.0 p.m.	2.8 millimetres in 0.4 second.

The strongest was the one on the 15th October, 17th Meiji; the next on the 22nd February, 13th Meiji.

The first of these began at 4.21.54 a.m. and lasted two minutes. The direction of motion, though varying, was mostly south-west and north-east, and its intensity was 95°10′ (there being no graduation beyond 25° the amount was guessed.) At this time, in Tokyo, though no house was destroyed nor the ground cracked, still the outside wooden framework of several store-houses fell down, a few walls of houses were cracked, here and there tiles fell from roofs, and furniture was in several instances upset or damaged. The shock of 1880 commenced at 0.50.15 a.m., and lasted one minute 26 seconds. The direction of motion, though varying, was

chiefly south-south-east and north-north-west, and its intensity was 78°. At this time, furniture was upset or damaged, the walls of common Japanese houses, brick houses, and store-houses were more or less cracked. The others mentioned in the list were also severe, but as their periods of vibration were long no damage was caused.

Direction of Motion of Earthquakes.

The nature of earthquake motion is not very simple, there being many other movements than those which are rectilinear and constant in their direction.

At the beginning of an earthquake the direction of motion seems to be uniform, but as soon as it grows stronger it may be in almost any direction. Though so confused, the disturbance is not without a principal direction, but sometimes the same earthquake may have two or three principal directions, as is shown in the table below:—

	Palmieri's?												Milne's.		
Directions. / Years	9th Meiji	10th Meiji	11th Meiji	12th Meiji	13th Meiji	14th Meiji	15th Meiji	Total	16th Meiji	17th Meiji	18th Meiji	Total	19th Meiji	Total	Grand Total
South—North	—	—	—	—	—	—	—	—	5	6	16	27	8	8	35
S.S.W.—N.N.E. ...	0	3	3	15	20	1	1	43	—	—	—	—	2	2	45
S.W.—N.E.	—	—	—	—	—	—	—	—	5	10	6	21	3	3	24
W.S.W.—E.N.E. ...	8	15	3	10	1	3	12	54	—	—	—	—	2	2	54
E.W.	—	—	—	—	—	—	—	—	8	25	7	40	14	14	54
E.S.E.—W.N.W. ...	12	12	22	9	7	26	3	91	—	—	—	—	5	5	96
S.E.—N.W.	—	—	—	—	—	—	—	—	3	5	4	12	13	13	25
S.S.E.—N.N.W. ...	0	4	1	11	24	7	14	61	—	—	—	—	3	3	64
Direction uncertain.	38	40	21	30	32	32	19	212	12	25	38	75	4	4	291
Total	58	74	50	75	84	69	49	459	33	71	71	175	54	54	688

This table shows that the direction of motion was most often between East South-East, and West North-West.

Nature of Earthquake Motion.

Although earthquake movements are horizontal or up-and-down, the velocities of the back and fore movements are often very different. Earthquakes when this motion is rapid often damage houses and furniture, but when it is slow they have rarely produced injurious effects. Thus during the 19th year of Meiji, the severe earthquakes were 19 in all, the slow moving ones 25,

whilst those which were so faint that their nature could not be ascertained were 10.

RELATION OF EARTHQUAKES TO ATMOSPHERIC PRESSURE.

There are many opinions as to the relation of earthquakes to atmospheric pressure, but nothing definite has yet been found. The following Table shows such relations for 531 earthquakes observed in Tokyo during nine years between the 11th and the 19th years of Meiji. (The earthquakes in this Table are not only those which occurred near Tokyo, but include all those which have been reported from different localities):—

ATMOS. PRES. MILLI.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
745	1	0	0	0	0	1	0	0	0	0	0	0	2
746	1	0	0	0	0	0	0	0	0	0	0	0	1
747	1	0	0	0	2	1	0	0	0	0	0	0	4
748	0	0	0	0	0	0	0	0	0	0	0	0	0
749	0	0	0	1	1	1	0	0	0	0	1	0	4
750	3	0	2	0	1	0	0	1	0	0	0	0	7
751	1	0	1	0	0	3	0	0	0	0	0	0	5
752	3	0	2	1	0	0	0	0	0	0	0	1	7
753	0	0	0	1	3	1	0	0	0	0	1	1	7
754	2	0	0	1	2	4	4	1	0	1	1	1	17
755	2	3	1	0	1	2	6	1	1	2	0	6	25
756	0	4	1	1	2	4	1	2	1	2	0	1	19
757	3	1	1	0	2	3	4	5	2	0	2	7	30
758	0	6	2	0	4	2*	5	1	2	3	0	3	28
759	2	4	3	2	6*	4	1*	5*	0	2	6	3	38
760	3	4	6	0	5	7	3	4	2*	2	2	2	40
761	3	7	3	3	4	1	1	7	3	7	2	3	44
762	6	2	3	3	2	1	1	1	6	2	5	5*	37
763	5*	5	8*	5*	5	1	0	0	4	1	6*	4	44
764	2	3*	6	0	1	2	0	0	2	1*	3	7	27
765	2	2	6	3	5	0	0	1	0	3	2	2	26
766	3	2	4	2	1	0	0	0	1	2	5	3	23
767	0	2	9	2	1	0	0	0	0	6	2	3	25
768	1	1	4	3	0	0	0	0	0	1	0	3	13
769	4	2	1	0	0	0	0	0	0	1	1	6	15
770	4	4	4	1	1	0	0	0	0	3	0	0	17
771	2	0	4	3	0	0	0	0	0	1	0	0	10
772	0	0	1	1	0	0	0	0	0	2	2	3	9
773	0	0	0	0	0	0	0	0	0	2	0	0	2
774	2	0	0	0	0	0	0	0	0	0	0	1	3
775	0	1	0	0	0	0	0	0	0	0	1	0	2
Total	56	53	72	33	49	38	26	29	24	44	42	65	531

* Means average atmospheric pressure.

From this Table we see that earthquakes are most frequent at 762 millimetres. This is about the average atmospheric pressure, which happens on very many days in a year. This observation therefore tells us but little. When the earthquakes which occurred when the atmospheric pressure was high or above the average, are compared with those that occurred when it was low, we find that they were rather more numerous when the barometer was low, the ratio being 46:44. Again, comparing the occurrence of earthquakes with the average atmospheric pressure of each month, the results are as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Above average pressure	23	15	43	17	28	17	6	16	17	21	19	34	234
Below average pressure	33	38	29	16	21	21	20	13	7	23	23	31	297
Total	56	53	72	33	49	38	26	29	24	44	42	65	531

In January, February, June, July, October, and November, there were many earthquakes when the atmospheric pressure was below the average; while in March, April, May, August, September, and December, we have the reverse. Comparing the number of earthquakes occurring as above indicated, we find that they are in the ratio of 48 to 52, the greater number occurring with the low barometer.

Examined when atmospheric pressure is increasing or diminishing, the results are as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Atmospheric pressure increasing ...	21	19	19	12	15	9	9	15	6	19	12	14	161
Atmospheric pressure diminishing..	15	20	24	12	11	7	6	1	5	13	13	26	153
Atmospheric pressure settled.........	20	14	29	9	23	22	11	13	13	12	17	25	208
Total	56	53	72	33	49	38	26	29	24	44	42	65	531

The earthquakes were most numerous when the atmospheric pressure was settled, less when it was increasing, and least when it was diminishing. Minutely speaking, in January,

August, and October there were many when it was increasing, and few when it was diminishing; in February and December there were many when it was diminishing and few when it was increasing, and in April the same in both cases. In March, May, June, July, September, and November, there were many when it was settled, and only a few when it was increasing or diminishing. This shows that the earthquakes were most frequent when the atmospheric pressure was settled.

Relation between Earthquakes and Temperature.

Temperature and atmospheric pressure have a close connection with each other. Generally speaking, the lower the temperature the greater the atmospheric pressure, the higher the temperature the less the atmospheric pressure. Whatever relation may exist between earthquakes and temperature may therefore, be simply the relation, looked at from a different point of view, between earthquakes and atmospheric pressure. In the following table 602 earthquakes observed during ten years from the 10th to the 19th years of Meiji (1877-1886) are compared with temperature:—

Temperature in Cent.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
6° below 0	0	1	0	0	0	0	0	0	0	0	0	0	1
5° zero	0	0	0	0	0	0	0	0	0	0	0	0	0
4° zero	1	0	0	0	0	0	0	0	0	0	0	0	1
3° zero	6	0	1	0	0	0	0	0	0	0	0	2	9
2° zero	3	1	0	0	0	0	0	0	0	0	0	1	5
1° zero	5	2	4	0	0	0	0	0	0	0	1	2	14
0° zero	6	5	5	0	0	0	0	0	0	0	1	6	23
1°	9	2	5	1	0	0	0	0	0	0	0	12	29
2°	3	8	6	0	0	0	0	0	0	0	0	6	23
3°	5*	5*	6	1	0	0	0	0	0	0	0	9	26
4°	7	10	8	1	0	0	0	0	0	0	2	8	36
5°	1	3	6	1	0	0	0	0	0	1	3	4*	19
6°	3	6	2*	2	0	0	0	0	0	0	2	5	20
7°	4	5	8	2	0	0	0	0	0	1	4	5	29
8°	2	7	5	5	1	0	0	0	0	0	4	2	26
9°	3	1	3	2	0	0	0	0	0	2	8	5	24
10°	0	2	8	3	4	0	0	0	0	2	5*	6	30
11°	2	0	2	0	2	0	0	0	0	1	2	0	9
12°	0	0	1	2*	2	0	0	0	0	6	2	1	14
13°	0	0	2	2	5	0	0	0	0	4	5	0	18

* Indicates average temperature.

Temperature in Cent.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
14°	0	0	2	5	1	0	0	0	0	4	3	0	15*
15°	0	0	2	3	6	0	0	0	0	8	2	0	21
16°	0	0	2	1	9	1	0	0	3	6*	0	0	22
17°	0	0	0	1	9*	6	0	0	2	4	4	0	26
18°	0	0	0	3	2	2	1	1	2	5	0	0	16
19°	0	0	0	0	3	4	0	1	1	1	0	0	10
20°	0	0	0	1	3	6*	0	0	1	1	0	0	12
21°	0	0	0	2	6	5	2	1	1	3	0	0	20
22°	0	0	0	0	4	5	3	2	8*	1	0	0	23
23°	0	0	0	0	0	6	6	5	1	1	0	0	19
24°	0	0	0	0	0	3	3*	3	0	1	0	0	10
25°	0	0	0	0	0	2	2	4*	1	0	0	0	9
26°	0	0	0	0	0	0	3	3	1	0	0	0	7
27°	0	0	0	0	0	2	2	3	1	0	0	0	8
28°	0	0	0	0	0	4	2	3	1	0	0	0	10
29°	0	0	0	0	0	1	2	2	2	0	0	0	7
30°	0	0	0	0	0	0	4	3	0	0	0	0	7
31°	0	0	0	0	0	0	2	1	0	0	0	0	3
32°	0	0	0	0	0	0	0	1	0	0	0	0	1
Total	60	58	78	38	57	47	32	33	25	52	48	74	602

* Indicates average temperature.

The average annual temperature in Tokyo is 14°. From the table we see that earthquakes were usually very frequent when the temperature was from 0° to 10°, and most frequent at 4° or 10° below the average temperature. The next was between 11° and 23°; at 17° there were 26; and above 24° not more than 10.

When compared with the average temperature of every month, the results are as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Above average Temperature	25	36	36	19	22	31	19	18	11	20	20	26	283
Below average Temperature	35	22	42	19	35	16	13	15	14	32	28	48	319
Total....................	60	58	78	38	57	47	32	32	25	52	48	74	602

In January, March, May, September, October, November, and December there were many earthquakes occuring below the average temperature; in February, June, July, and August there were many occurring above it; in April, the same number

occurred both above and below it. Generally speaking, earthquakes were more frequent when the temperature was below the average rather than when it was above it, the ratio being as 60:40; also in every month there were more earthquakes when the temperature was below the average, the ratio being as 53:47. The following table shows the frequencies of earthquakes when the temperature was rising, falling, or settled :—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Temperature rising	24	19	24	10	21	19	6	10	5	18	15	34	205
Temperature falling	31	29	39	18	31	22	22	21	15	27	31	35	321
Temperature settled	5	10	15	10	5	6	4	2	5	7	2	5	76
Total....................	60	58	78	38	57	47	32	33	25	52	48	74	602

As shown in the Table, earthquakes were numerous when the temperature was falling, few when it was settled, and tolerably frequent when rising. The same holds good in the case of every month. But in April and September there was the same number whether the temperature was rising or settled.

General Observations.

From a paper in this volume entitled "On the distribution of earthquake motion in a small area," it will be seen that even in Tokyo earthquakes have often occurred which have only shaken a superficial area of not more than 4 or 5 square miles. From this it follows that if observers and observations are not closely situated with regard to each other many earthquakes may pass unrecorded. Another cause tending to diminish the number of records is that many observers may be situated on low, soft ground where, partly in consequence of the length in period of the motion on soft ground, many shocks pass by unnoticed. Then again observers provided with instruments record more disturbances than those who are without instruments.

If, therefore, more instruments were distributed throughout Japan and the number of observers increased, basing my opinions upon observations made in Tokyo (see the above men-

tioned paper) I fancy that, instead of only recording about 480 shocks per year, the number might easily be increased to 1,000.

The reason that more earthquakes have been observed during the night than during the day, is probably owing to the fact that during the day people are usually moving about or so engaged that they are not so favourably situated to observe shocks as they are during the night. The figures giving the total area of ground which is shaken each year are probably very nearly proportional to the dissipation of seismic energy in the years to which they refer; and it will be interesting to notice how these figures, either as referring to the whole country or to particular seismic districts, follow each other in successive years. In seismological history we have many instances, as at Comrie in Scotland and at Kyoto in Japan, where seismic energy has become markedly less during historic times. A table of areas shaken in successive years might in cases like these indicate the *rate* at which energy was being dissipated. Farther, if we had a considerable number of seismographs giving us the number, amplitude, and period of all the vibrations which occurred in the shocks recorded during a given period, on the assumption of the disturbance as it radiated being practically superficial, as it appears to be, we should then be in a position to represent the seismic energy in mechanical units.

This leads us to ask whether the equivalent of this in heat units has any connection with the loss of heat, and consequently the heat gradient in the district where the observations have been made.

The variations in the distribution of seismic disturbances in successive years promise to yield results of considerable scientific importance.

An investigation which might be made with regard to the 228 shocks which originated on the coast or beneath the sea, would be to determine whether they had any connection with

the tides or currents on the coast. In an investigation which I made on this subject I found that the earthquakes which occurred at low water were 11.2 per cent. more numerous than those which happened at high water. (Trans. Seis. Soc., Vol. VII., Pt. II., p. 83.)

Another point of great importance in connection with any theory which may be advanced to explain earthquake action, which this report confirms, is that the ordinary earthquakes do not appear to be immediately connected with the presence of volcanoes.

A point I would suggest is that the records of a number of earthquakes coming from approximately the same origin be analysed separately. For this purpose two or three distinct sets of analysis might be made for the chief seismic *foci* in this country.

The great value of the report upon earthquakes which have been recorded in Tokio, is that it places before us a large number of trustworthy observations which are at our disposal for reference or analysis. Chaplin, Knipping, Knott, myself, and others have during previous years analysed a portion of these records, the results obtained being, so far as they can be compared with the series before us, very similar. In the present report, as in that by Prof. Sekiya for 1885, the classification of earthquakes according to four seasons, each of three months, commences with Spring, embracing March, April, and May. In my own tables and those of the late Mr. Mallet, Spring includes April, May, and June. Each season is therefore one month different in the present set of tables to the tables constructed previously. The results arrived at are, however, practically the same; namely, that during the winter and spring months, or during the cold months of the year there is a greater frequency of earthquakes than there is at other times in the year.

The comparison of earthquakes with the hours at which they have occurred, although not showing any thing very pro-

nounced, is an analysis to which Japanese earthquakes have for the first time been subjected.

In speaking of the intensity of earthquakes, the shock of October 15th, 1884, is regarded as the most severe which has during recent years been recorded in Tokio. So far as the record given by Palmieri's seismometer may be taken as a guide, this is certainly correct, but if we consider the damage which was the result of any of our recent earthquakes, then we must conclude that the most destructive earthquake was that of February 22nd, 1880.

The intensity recorded by Palmieri's instrument is simply dependent upon the height to which mercury in a tube has oscillated and moved a float connected with an indicator on a dial. This height is, as has often been pointed out, greatly dependent upon the synchronism or non-synchronism of the earthquake movements with the natural period of the mercury in the tube.

This being the case it is clear that a comparatively feeble earthquake might sometimes indicate a greater number of degrees than a much more destructive disturbance.

I am glad to see that more extended observations upon the principal direction of earthquake motion in Tokio confirms previous investigations (see Notes on "Recent Earthquakes of Yedo Plain, and their effects on Certain Buildings," by J. Milne; Trans. Seis. Soc., Vol. II., p. 38) these results being of importance to those who deal with construction.

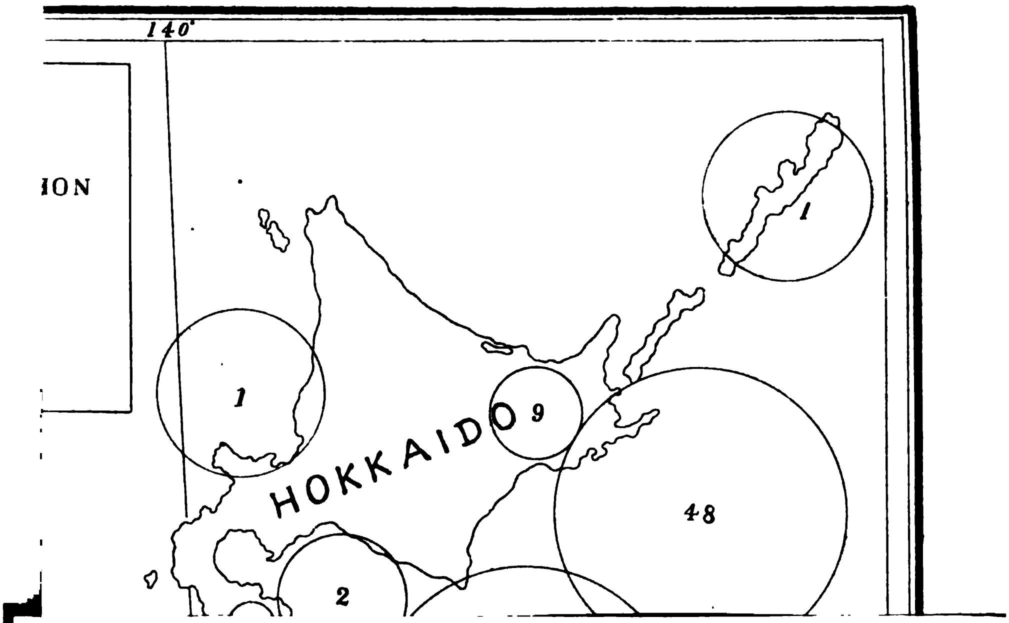
A more interesting analysis respecting the occurrence of earthquakes and fluctuations of the barometer than the tables given, would be a comparison between the occurrence of earthquakes and barometric gradients, such gradients being measured across an area of considerable extent and in some known direction relatively to the centre of the districts shaken. It is not unlikely that many earthquakes will be found to accompany a steep gradient, and this may account for the observation, first pointed out by Knipping, that earthquakes

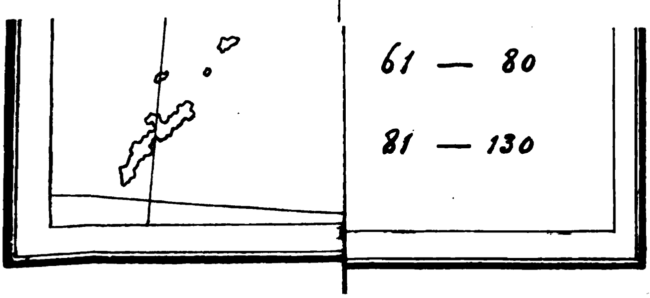
often accompany high winds. (See the paper on "Earthquake frequency," by Dr. C. G. Knott referred to at the commencement of this Report).

The chief value of the tables showing the relationship between earthquakes and changes in temperature may be to dispute a wide-spread belief that these two phenomena have an intimate connection.

Now that earthquakes at the Imperial Meteorological Observatory are altogether recorded as diagrams of motion, it is to be hoped that future reports will contain examples of these diagrams, and that tables giving amplitude, period, average period or say the number of waves in ten seconds, intensity, area shaken, distance, and direction of approximate origin may be given for all the earthquakes which are recorded.

E II.

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ABSTRACT OF A THEORY AS TO THE CAUSE OF EARTHQUAKES.

By Dr. Stanislas Meunier.

[Read March 19th, 1889.]

It is clear that, as regards their causes, volcanoes and earthquakes are to be grouped together—with the exception of small earthquakes due to purely superficial causes. It is also clear that water or steam plays an essential part in all such seismic phenomena.

The earth's temperature rises as we descend, attaining at moderate depths a degree far exceeding that required for the transformation of water into steam. If such a transformation took place suddenly, a violent explosion would necessarily be the result, and seismic effects would be produced.

The difficulty is to account for the preliminary accumulation of liquid water in regions too hot for its existence except in the form of steam. For clearly the water must first penetrate into these regions, and then be violently vaporised.

A gradual infiltration of water, through the ocean bed for example, is evidently quite incapable of satisfying the conditions, and would besides fail to account for the invariably intermittent character of seismic activity. All the conditions, however, seem to be met by the following very simple hypothesis. Consider first a volcanic and second a non-volcanic region.

First, a volcanic region. At some depth below the surface there is a hot focus; and near the surface we have water and

moist rocks. Between these regions there must be a solid barrier free from moisture, free because of its high temperature. Now let a communication be established between the highest and lowest regions by means of a crevice forming in the intermediate barrier. This will of necessity be accompanied by a pulverisation of rocks, and fragments, more or less saturated with water, will almost certainly fall from the surface crust down into the hot volcanic depths below. Thus liquid water will be rapidly conveyed to regions so hot as to cause it rapidly to vaporise with all the effects of an explosion.

Many geological and seismological facts fit naturally into this hypotheses. The faulted condition of rocks shows that crevices do form in the manner supposed. Then if the falling fragments reach regions which are moderately hot, the transformation of water into steam will take place gently. On the other hand, if they fall into highly heated regions amongst molten rocks, the bubbling steam may raise the whole fluid mass; just as the escaping carbonic acid gas causes champagne to effervesce. Between these two extremes all other cases fall.

Second, a non-volcanic region. Even though there is no volcanic centre, yet it is admitted that we have subterranean heat everywhere. This, in combination with faulting, will lead to very similar effects. Many facts, which observation has established, seem to admit of ready explanation according to this hypothesis. For example, pronounced seismic activity in recently faulted countries; the elongation of an epicentre parallel to shore or mountain ridge, that is, in the probable direction of faulting; the occurrence of earthquakes along the known lines of great faults, as in Western Switzerland from the Lake of Constance to the Lake of Geneva; the intermittent character of earthquake shocks in countries liable to seismic action; and, perhaps most important of all, the propagation of the point of origin of a shock along a fault. This last effect will take place when a fault gradually widens out in

a given direction, the successive earthquakes due to the falling in of saturated rocks originating at points succeeding each other along this direction. Thus, in 1811, a series of earthquakes beginning at the mouth of the Mississippi worked up in the course of a year to the Great Lakes of Canada.

In the discussion which followed, Mr. Milne remarked that he did not see the necessity of requiring fissures for the penetration of water into the crust of the earth, since the remarkable experiments of Daubrée show that by capillary action water can soak through rocks against high steam pressures.

OBITUARY NOTICE.

VISCOUNT MORI ARINORI.

[Read March 19th, 1889.]

Since our last meeting, our Society has suffered a severe loss in the death, by assassination, of its President, Viscount Arinori Mori, Minister of Education. To the deep general interest which Viscount Mori took in things educational, he added a keen appreciation of all new and progressive ideas. No doubt this particular mental trait disposed him to take a special interest in the young science with which our Society deals. In 1885 he was elected our President; and, although his manifold duties prevented his regular attendance at our ordinary meetings, his strong sympathy in our aims and labours was attested in many ways. Soon after his appointment as Minister of Education, the chair of Seismology in the Imperial University was established. Last year, at his express wish, a Committee of architects, engineers, and other representative scientific men, was called together to consider the methods of construction best fitted to resist earthquake motion. Several preliminary reports have already been presented; but the Committee is still engaged in making experiments and collecting information. The final report, when handed in to the Central Government, will be of its kind, the most voluminous and complete yet written, and will always bear testimonny to the zeal and forethought of the late Minister of Education. When any special lectures on Seismology were given, Viscount Mori was rarely absent;

and in these and other ways he gave substantial support to Seismological investigations.

Viscount Mori was well versed in Natural Science and Literature, more particularly in History and the study of Languages. Under his *régime* in the Educational Department, the whole system of education throughout the country has been placed on a new basis and powerfully developed. His encouragement of gymnastic exercises as a means of strengthening the physique of the students of this empire, and his steady regard to the influences that mould them, intellectually and morally, are especially worthy of mention. The increase in the number of schools, and their improved status throughout the country, are largely to be traced to Viscount Mori's unwearied exertions. One of his latest schemes was the making of schools as far as possible self-supporting.

Viscount Mori's sad and unexpected death on February 11th has occasioned a serious loss to all connected with education in Japan; and we, of the Seismological Society, have to mourn the loss of a President that could ill be spared.

CONTENTS.

Transactions of the Seismological Society of Japan.

Vol. XIII., Part II.

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TRANSACTIONS

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position admirably suited for our purposes. Though so close to the volcanic focus, the spa had escaped total destruction, being situated at the back of the crater, and screened by a hill-brow from the direct effects of the explosion. As might be expected, our surveying and other works on the summit, the fruits of which are embodied in this paper, were not unattended by discomforts and difficulties—such, for example, as indifferent food, breakneck ascents and descents, foul vapours, chilly nights, and long sultry summer days spent in scrambling over a scorched and barren crater.

Soon after the eruption we sent letters of inquiry to a large number of schoolmasters and local officers in the neighbouring provinces; accounts given by other observers, as well as those published in newspapers, were also duly considered. The information embodied in the answers to our letters was very valuable for the purpose of this paper, especially in preparing Plate X., and we take this opportunity of expressing our sincerest acknowledgments to all who thus helped us. We also tender our best thanks to the colleagues and friends who have since assisted us, by suggestions and otherwise, especially to Major-General Palmer, R.E., for kindly helping us with our English and for many valuable hints.

The questions we asked in our letters were mainly as follows:—The names and addresses of the observers. The times at which they first noticed the eruption. Did they hear the sound of the explosion? Its nature, duration, loudness, &c. Did they see steam (commonly called smoke) rising up in the air? Its colour, height, form, &c. Did they see lightning in the steam, or fire on the volcano? How did the lightning or fire look? Did volcanic dust fall? Its thickness, colour, consistency, structure, &c. Were there any earthquakes either before or after the eruption? Their times of occurrence, intensity, duration, nature, &c. The state of lakes, rivers, and springs before and after the explosion. The meteorological conditions, especially the force and direction of the wind.

Any other information bearing on, or which might seem to bear on, the eruption was also asked for. The answers to these questions are given in a tabular form at the end of this paper.

Bandai-san, considered Topographically and Geologically.

In Northern Japan, there run along the Pacific seaboard two principal masses of mountains, chiefly composed of crystalline and older rocks. The more northerly of the two, on the eastern side of the Kitakami River, has been named by Dr. E. Naumann the Kitakami Mountain-land, and the other, situated to the east of the Abukuma River, the Abukuma Mountain-land. These two mountain-masses are remarkably similar in their geological structure, and the principal direction of strike is north and south. They are very old formations, consisting of granite, granite-gneiss, gneiss, and other crystalline schists, together with thick accumulations of Palæozoic strata, much folded and faulted, and some patches of Mesozoic strata not less disturbed. We have, in fact, the relics of old land, the principal features of which must have been determined at the end of the Mesozoic Era, and much of which has, no doubt, been subsequently denuded away.

On their western sides, the two mountain-lands face broad valleys, in which the rivers already mentioned run in a meridional direction—the Kitakami from north to south, and the Abukuma from south to north—and along which passes the chief highway of Japan. The valleys separate the Abukuma and Kitakami ranges from a high ridge which, traversing the middle of Northern Japan, forms structurally the backbone of the region, and constitutes the main water-shed between the Pacific Ocean and the Japan Sea. This central ridge owes its origin to volcanic effusions of comparatively younger date, and consequently the natural barrier thus created is made up mostly of prominent volcanic peaks, and differs in its features

from the neighbouring old land. The more important of the volcanic peaks are, Osore-yama and Yake-yama on the extreme north of the main island, and thereafter Ganju-san, Komaga-take (Province of Rikuchū), Zoō-zan, Azuma-san, Bandai-san, Nasu-dake, Shirane-san (Province of Shimotsuke), Akagi-san, &c. These mark the course of the line of weakness along which terrestrial disturbances of varying degree have manifested themselves, in times past, attaining their climax during the Tertiary Era, and thereafter declining into their present state of comparative quiescence.

Bandai-san (lat. 37° 36′ N., long. 140° 6′ E.) is situated in the Yama District (*kōri*) in the Province of Iwashiro, immediately adjacent to the Abukuma mountain region, a part of which, formed of granite and gneiss, borders the east bank of the river Nagase that runs immediately past the foot of the volcano. Besides Bandai-san, there are in this part of the country several other volcanoes, both active and extinct, as shown in Pl. X.; the line of principal volcanoes belonging to the central ridge of Northern Japan, already referred to, is shown in the same plate by a broken line. On the north-east of Bandai-san are Dake-yama and the Azuma-san group, the latter consisting of three principal peaks called the Eastern, Western, and Middle Azuma; while on the south are Nasu-dake, Takahara-yama, &c. Immediately north-west of Bandai-san there is a small lake called Okuni-numa, at an elevation of 1,065 m. above the sea-level, and surrounded on all sides by ridges, the highest of which is called Nekoma-yama, and rises 305 m. above the lake. Judging from its features, Okuni-numa is unquestionably an old crater. Between it and Bandai-san there stands a round-topped hill, till lately overgrown with forest, and known as Marumori-yama, which is apparently a small volcanic cone. The few naked tree-trunks, stripped of branches and leaves, that are now to be seen on this hill-top vividly attest the severity of the recent eruption.

From the fact that the older rocks of the Abukuma moun-

tainland underlie the volcanic groups in the vicinity of Bandai, it seems reasonable to infer that the volcanoes originated on the fractured edges of the old formation.

Though all of the volcanoes that have been in eruption in recent times are shown as active on Plate X., it is to be understood that such activity never exceeded intensified solfataric explosions, disturbing the upper crust alone. The late explosions of Nasu-dake and Azuma-san were of this class only, neither lava nor pumice having been ejected. The extreme volcanic energy which once raged in the district of Bandai seems to have gradually waned down to the present time. Denuding action has evidently played a more prominent part than plutonic agency in changing the forms of the mountains, and the decomposition of the rocks has produced a thick layer of soil, supporting a dense forest-growth, and concealing the old lava-flows and scoriaceous ejections which attest the volcanic origin of the hill-masses. Peasants worked daily among the green forests of Bandai, to collect fuel and to fell trees, wholly unsuspicious of the calamity that hung over them.

The district about Bandai-san is made up principally of tufaceous deposits and sheets of volcanic rock, forming the basis of an elevated area known as the Aizu Plateau, which includes the districts of Yama, Aizu, Kawanuma, and Ōnuma, in Iwashiro, its average height exceeding 500 m. above the sea-level. This plateau is surrounded on all sides by mountains of volcanic origin. On its southwest border stand the extinct volcanic peaks of Hakase-yama, Mikagura-dake, &c., and on the south the conspicuously flat-topped Nunobiki-yama, formed of volcanic sheets. Among these mountains are found numerous hot-springs, more than 30 of which have been counted.

The streams which rise in the surrounding mountains discharge into a depression on the south side of Bandai, there forming the Lake Inawashiro, which is one of the largest in Japan. This lake, the surface of which is 496 m. above the

sea-level, is not a true crater-lake as is sometimes supposed. Its principal feeder was the river Nagase, flowing from the northern part of Bandai. The upper course of this river was, however, entirely stopped by the falling *débris* during the recent eruption, and the lake is now supplied mainly by its tributary, Sukawa, flowing from Dake-yama. The lake discharges northwestward, at the village of Tonokuchi, by a stream which flows through the Aizu Plateau under the name of Nippashi-gawa for about 19 kilometres, then joining the Aka-gawa. The latter stream collects all the waters of the Aizu Plateau, and finally runs into the Japan Sea near the port of Niigata. Recently another outlet was made on the eastern side of the lake, by means of a canal for irrigation.

It seems probable that the Inawashiro Lake fills up a depression formed by evisceration of the ground, resulting from the copious outpourings of volcanic products in its vicinity, notably those of Bandai. The origin of the lake, according to current tradition, is ascribed to great terrestrial disturbance which took place in the ninth century. The districts known as Tsukinowa and Sarashina, consisting of 49 villages, are said to have been submerged on that occasion.

The name Bandai-san is usually given to a group of peaks, consisting of Ōbandai, Kobandai (lately destroyed), Kushigamine, and Akahani-yama, surrounding an elevated plain called Numano-taira. (Pl. I.) This group, standing on the northern side of Lake Inawashiro, forms a very conspicuous object in the landscape, and displays the characteristic outlines of a volcanic mountain. When seen from the southwest side, from the town of Wakamatsu, it appears as a single pointed peak. It has sometimes been called the "Fuji of Aizu," from its resemblance to the well known Fuji-yama. Ōbandai, or Great Bandai, is the most prominent of the peaks, its summit being 1,840 m. above the sea-level. It presents a highly rugged and precipitous escarp toward the Numano-taira, exposing volcanic strata which are the results of accumulations of augite-an-

desitic lava and scoriæ during its period of activity. Viewed at a distance from the east, Ōbandai has a highly characteristic appearance, descending by a very steep slope toward the central plain and by a gentle one in the opposite direction. Kobandai, or Little Bandai, was less known, on account of its being situated far away from the inhabited portions of the Aizu Plateau, and being also partly screened by its more prominent sister peak. From the latter fact it appeared to be lower than Obandai, and was therefore so regarded ; and hence its name. But careful examination has shown that they were probably of almost identical height, as will appear farther on.

It is probable that the plain Numano-taira is the remains of the original crater—Atrio—and that the several peaks above mentioned are parts of the Somma-wall which encircled it. But gradual denudation during long periods of quiescence, together with occasional rendings of the crater-wall when explosions took place, have brought about the present form, namely, that of separate masses presenting more or less conical shapes. In the Numano-taira, or "plains with ponds," there were several small lakes or pools, as is usual in craters of this nature. Nearly in its centre, there existed before the eruption a solfatara on a small hillock called the Iwō-yama, or "sulphur mount," from which sulphur was collected by the neighbouring villagers. The plain was also covered with dense forests, which were destroyed on the 15th of July.

The flanks of Bandai are cut into numerous channels called "sawa." The largest of them is that known as Biwa-sawa, which opens eastward from the Numano-taira. It was down this ravine that the smaller stream of mud and rock descended in the late eruption. Seen from the east, it presents a very conspicuous appearance. Fig. 2, Pl. III., is a sketch made of this part of the mountain immediately after the eruption. From our point of view we had a magnificent prospect of Ōbandai, with its rugged and precipitous wall on the northern side. The plain of Numano-taira is seen to terminate in a very steep cliff,

known as Futatsu-iwa, at which place the water of the lakes in the above plain made a sudden leap, forming a high water-fall. Immediately below this is a small depression called Hikage, which has been regarded by some as a secondary crater of the late eruption. Another large ravine is that lying between Ōbandai and Akahani-yama, opening southward, and named Katsura-sawa. There is also a bare glen on the southern flank of Ōbandai, known as Kara-sawa. These ravines or valleys may be considered to have been chiefly modelled by the paroxysmal explosions which, as the history of the mountain tells us, took place at intervals in past times. Denudation, however, has doubtless modified their original forms. The same remarks may be held to apply to the topographical features of the whole mass. For, not only must the original form of the mountain have suffered by the successive eruptions, but the *débris* thus produced, obstructing the water-courses, must have gradually brought the surface to its present form. Some of the outbursts would seem from the history of Bandai-san to have been very similar in character to that of the 15th of July last.

The hot-springs on the north-western side of Bandai, known as Bandai-no-yu, were latterly the principal remnants of the volcanic forces which once raged with so much vigour. There were three of these springs, all celebrated for their curing effects upon various diseases. They were known as Kami-no-yu, Naka-no-yu, and Shimo-no-yu, respectively meaning the upper, middle, and lower bath, where small huts had been constructed for the accommodation of bathers, who flocked thither in summer from various parts of the neighbouring district. They were sulphur springs originating in solfatara formed by the issuing of steam and sulphuretted hydrogen from numerous rock-fissures.

Several years before the eruption Professor J. Milne,* of the

* The Volcanos of Japan—Transactions of the Seismological Society of Japan, Vol. IX., Part II.

Imperial University, ascended Bandai-san, when he took a sketch and described it, classifying it as an active volcano.

TRADITIONS AND HISTORY.

According to tradition, Bandai-san was originally a single massive peak, the summit of which was burst open in olden times by a volcanic eruption, and split into several peaks, the event being productive of a terrible catastrophe. The *débris* of the explosion descended on all sides of the mountain, and the two districts Tsukinowa and Sarashina, containing some fifty villages, were engulfed beneath the area thereafter occupied by Lake Inawashiro. This account of the splitting of one large mountain into several minor peaks is interesting, as it agrees with the suppositions suggested by the structure of the volcano. For, as has been previously explained, the several ridges together constituting the Bandai group surround an elevated plateau which has all the appearance of an old crater.

Another tradition, apparently referring to the same event, says that in the first year of Daidō (806 A.D.) Lake Inawashiro was suddenly formed, and in it a small island, now called Okina-shima, appeared.

Religious traditions, on the other hand, not unnaturally connect the catastrophe with demoniacal agencies. A Buddhist temple in a village near Bandai-san contains a document, said to chronicle its founding, which runs thus :—" In olden times there used to dwell about Bandai devils who did much harm to the inhabitants ; in the year of Daidō numbers of people living at the foot of the mountain were swallowed beneath the earth, and there was left a great lake (Inawashiro). The reigning Emperor, in order to subjugate the evil spirits which were probably the cause of all these terrestrial mysteries, despatched the famous priest Kūkai, who, on arrival at the spot, performed ten days' secret prayer to Buddha, when the devils were compelled to vacate Bandai and to flee to the neighbouring moun-

tains. In commemoration whereof, Kūkai caused this temple of Dainichi-ji to be built."

Several ancient records describe the mountains as having at various times smoked and ejected fire and poisonous vapours. Such accounts are highly interesting, especially when we consider the volcano's apparent quiescence for ten centuries. We give below translations of some of the records published by the Geographical Bureau, with remarks on them.

The *Tōgoku Ryokōdan* (東國旅行談, Travelling Tales in Eastern Provinces) says :—" To the east of Lake Inawashiro there stands a steep peak called Bandai-san; from its high summit ascend blazing fire and smoke, as if to burn the firmament." This account is followed by an illustrative sketch, as in the accompanying wood-cut, of the volcano belching forth fire and smoke.

In the *Ōu Benranshi* (奧羽便覽誌, Handbook on Ōu Provinces) the following account is given: "Aizu-yama commonly called Bandai-san, lies to the east of Lake Inawashiro; from its top ascends burning smoke."

It sounds strange to hear of flame and fire; but we ought not to put much confidence in the tales of travellers, which are too often exaggerated and grossly inaccurate. Though the phenomena caused by streams of molten lava in volcanic eruptions are commonly spoken of as presenting the appearance

of flames and fire, we do not find in Bandai-san any indication of lava-flows that can have taken place within historical times. It may be added, however, that there are cases on record in which flames caused by the combustion of gases have been a feature of volcanic outbursts.

The *Shinpen Aizu Fūdoki* (新編會津風土記, Accounts of Aizu) says:—"In olden times the destruction of a part of Bandai-san gave rise to Akahani-yama. The effects were very violent and extensive; earth and stones falling down dammed the stream of Sugawa and inundated Hibara." To the north-west of Oda village there are places respectively called Ōnamiyose (large wave beach) and Konamiyose (small wave beach). These localities, it appears, were formerly washed by the waters of lakes formed on the occasion above referred to, which, however, subsequently disappeared. As to the cause of this destruction of Bandai-san, it is not clear from the description whether it was volcanic or otherwise, but the phenomena exhibited seem to have been similar in character to those of the late eruption. Besides, there are authentic records of other terrestrial disturbances of much younger date, though perhaps of less magnitude, which have occasionally troubled this part of the country. These accounts seem to attest successive outbreaks of the same store of energy that wrought such havoc on the 15th of last July.

In the 8th month of the 16th year of Keichō (1611), a violent earthquake occurred at Bandai, and the fall of earth and rocks that was produced by this convulsion dammed up the river Nippashi, the outlet of Lake Inawashiro, and resulted in the formation of three new lakes. Water issued in great quantities from fissures opened in the ground. Accumulations of water, caused by the stoppage of streams, formed several other lakes, and in one place a waterfall of considerable height. In the villages of Matsuno and Terauchi some temples were otherthrown; and there were innumerable damages of other kinds. In spite of the efforts of Gamō, the ruling Daimyō, who em-

ployed large numbers of men to cut an outlet for the accumulated waters, inundation spread over the districts Yama and Kawanuma, producing a lake at Yamazaki; and it was not until after several engineering attempts that a passage was effected, by the aid of which about one-half of the inundated area was at length reclaimed.

During the period Hōreki (1751-1783), another convulsion took place in Mount Hanzawa, and created the present lake of that name.

The last recorded disturbance, although its particulars are not known, is said to have taken place about 80 years ago, when several lakes in Numano-taira were filled up, and great quantities of *débris* descended by the Biwa-sawa. Traditions and tales relating to this event were cherished with superstitious fear by the peasantry of the region, and listened to with wondering awe by the children, until there fell upon them the yet more terrible catastrophe of last July, which we now proceed to describe.

Eruption and Attendant Phenomena.

On the morning of July 15th, 1888, the weather in the Bandai district was fine, there being scarcely a cloud; and a gentle breeze was blowing from the W.N.W. Soon after 7 o'clock, curious rumbling noises were heard, which the people thought to be the sound of distant thunder, often heard among the mountain-tops. At about half-past 7, there occurred a tolerably severe earthquake, which lasted more than 20 seconds. This was followed soon after by a most violent shaking of the ground. At 7.45, while the ground was still heaving, the eruption of Kobandai-san took place. A dense column of steam and dust shot into the air, making a tremendous noise. Explosions followed one after another, in all to the number of 15 or 20, the steam on each occasion except the last being described as having attained a height above the

peaks about equivalent to that of Obandai as seen from Inawashiro, that is to say, some 1,280 metres, or 4,200 feet.

The last explosion, however, is said to have projected its discharge almost horizontally, towards the valley on the north. And, considering the topography of the mountain and the form of the crater, it is probable that previous discharges were also more or less inclined to the vertical, in a northerly direction. The main eruptions lasted for a minute or more, and were accompanied by thundering sounds which, though rapidly lessening in intensity, continued for nearly two hours. Meanwhile the dust and steam rapidly ascended, and spread into a great cloud like an open umbrella in shape, at a height equal to at least three or four times that of Ōbandai. This cloud was gradually wafted away by the wind in a southeasterly direction. At the immediate foot of the mountain there was a rain of hot scalding ashes, accompanied by pitchy darkness. A little later, darkness was still great, a smart shower of rain fell, lasting for about five minutes. The rain was quite warm. These phenomena, as well as the terror and bewilderment which they caused among the peasantry, were described in thrilling terms by the newspapers of the day. While darkness as aforesaid still shrouded the region, a mighty avalanche of earth and rock rushed at terrific speed down the mountain slopes, buried the Nagase valley with its villages and people, and devastated an area of more than 70 square kilométres, or 27 square miles.

Account of an Eye-witness.

Mr. Tsurumaki, a priest of Echigo, who was staying at the Naka-noyu spa on the edge of the crater at the time of the eruption, and who escaped death almost miraculously, sent us soon afterwards the following interesting and minute account of his terrifying experience :—"I started from my native village on the 8th of July, in company with four of my friends, for Bandai-san, and arrived there on the 12th, *i.e.*, three days

before the catastrophe. I had been there before, in July, 1885, when I stayed three weeks. On the day of my recent arrival (the 8th) the fog was unusually dense, and the volume of steam at Kami-noyu seemed to have lessened. On the 13th the fog was denser still, and remained so till the evening. The 14th was a bright day, the fogs of the previous days having cleared up. From about 10 o'clock in the morning of this date the flow of the spring began to diminish. But the fact that the amount of discharge is smaller in fine weather and larger in cloudy days is well-known among bathers, so that we gave no heed to it. The morning of the 15th, which was the fatal day, dawned with a bright and pleasant sky, and the flow of the spring was as usual. At about 8 o'clock, however, there was a fierce convulsion of the ground, and we all rushed out of the house. In about 10 minutes (seconds?), while we were fearfully wondering what was the matter, a terrible explosion suddenly burst out from the slope of Kobandai, about one *chō** above a place at which steam has been issuing from time unknown. This was followed by a dense mass of black smoke, which ascended into the air and immediately covered the sky. At this time, showers of large and small stones were falling all about us. To these horrors were added thundering sounds, and the tearing of mountains and forests presented a most unearthly sight, which I shall never forget while I live. We fled in all directions, but before we had gone many metres we were all thrown prostrate on the ground. It was pitchy dark; the earth was still heaving beneath us; our mouths, noses, eyes and ears were all stuffed with mud and ashes. We could neither cry out nor move. I hardly knew whether I was dead or in a dream. Presently a stone fell on my hand, and I knew I was wounded. Imagining, however, that death was at hand, I prayed to Buddha. Later, I received wounds on my loin, right foot, and back. After the lapse of an hour the stones ceased to rain and the atmosphere had cleared from darkness to a light like moonlight.

* One *chō* is nearly equal to 109 mètres.

Thinking this a fine opportunity to escape, I got up and cried, 'Friends, follow me!'; but nobody was there. When I had descended about two *chō*, there was a second, and after another *chō*, a third explosion. In these sand and ashes were ejected, but no stones. I reached Ōdera at noon, and there I received surgical treatment, etc."

Deluge of Rock and Earth.

The most striking feature in the whole of this eruption was the deluge of rock and earth. Notwithstanding the violence of the phenomena, and the completeness with which the mountain was destroyed, the nature of the eruption was comparatively simple. The destructive agency was merely the sudden expansion of imprisoned steam, unaccompanied by lava flows or pumice ejection. When the explosion took place, a considerable amount of rocks and earth was projected into the air, and a part diffused in the form of dust, but by far the greater part of the bulk of Kobandai was just split into mighty fragments, which were thrown down much after the manner of a land-slip. Descending the mountain sides with ever accelerating velocity, the components of these avalanches were dashed against obstacles in their way and against each other, and were thus rapidly reduced to confused masses of earth and rocks. The loose and friable *débris* thus produced ultimately lost its adhesive power, and may have been compared with a little exaggeration to sand. If we suppose a mass of some 1.21 cubic kilomètres, or 1,587 millions of cubic yards (which was the actual volume of the mountain destroyed), of sand to be suddenly precipitated from a lofty summit, it would flow down the sides in a torrent not very unlike that of water. That the earth and rock *débris* did flow down in this way we were convinced by examining the actual state of things on the spot, and more particularly by witnessing afterwards with our own eyes a very similar phenomenon, though on a vastly smaller scale.

One day, while we were at work in the crater, a huge slice of the precipitous wall of rock that had been bared by the explosion fell suddenly and crashed with a tremendous uproar down the steep incline beneath. This slab fell from a place about 300 mètres high. The great masses of earth and rocks were shattered as they fell, and broken up into pieces, ever growing smaller as they descended. The behaviour of this pulverized mass resembled the rush of a headlong torrent. Although boulders measuring 10 mètres or more in diameter were mixed up with finer matter, as a whole the movement approximated to that of a fluid. No words can describe the fierceness and force of that impetuous downpour—its mad surging this way and that, and the bold leaps with which it would now and then bound over low ridges that hindered its progress, and shoot onward down the neighbouring depression. It was a magnificent but somewhat awful sight to witness during an afternoon's ramble.

In a like manner probably, but on a vastly more gigantic scale, the stream of materials on the 15th of July ran down the slopes of Bandai-san, dividing as it went into two principal branches.

The main branch flowed northward. Kobandai, it must be explained, sloped on the north towards the Nagase valley, in an unbroken descent; and, as the mountain burst on this side, the *débris* dashed with great violence down this northern slope in the direction of Hibara, 9 kilomètres away. One part of the torrent actually ran *up* the valley, toward the source of the River Nagase, burying on its way the three hamlets of Akimoto, Hosono, and Osuzawa. A part, however, of the pulverized earth ran *down* the valley; reaching Kawakami spa and submerging it to a depth of probably more than 40 mètres, it proceeded southward to Hinokuchi, 3 kilomètres farther down.

The other and much smaller branch took quite a different route, making an angle of nearly 120° with the main stream.

It came down by way of Numano-taira, through Biwa-sawa, rapidly spreading as it descended, and dividing into three minor ramifications. The southernmost of these just reached the village of Miné, overwhelming nearly one-half of the houses, with their inmates. Fig. 1 of Pl. III. is a view taken from the outskirt of Inawashiro, at a distance of nearly one kilomètre from the mud field, showing the village of Miné in front, and the avalanche (d) of rock and earth descending upon its prey. Fig. 1 of Pl. IV. is another and nearer view of this mudfield.

The combined volume of these two great streams entirely covered an area of 27 square miles, or 70 square kilomètres, with a solid sea of mud and rock, beneath which were buried all the features of the landscape, together with people, cattle, and other living things. The grey tint of Pl. I. marks the area thus devastated.

The descending matter must have moved with great velocity. By some survivors it was described as having reached their vicinity almost instantly after the eruption. From several calculations, made by comparing the time of the explosion with the times at which the streams of *débris* arrived at different points, we roughly estimated the average speed to have been 77 kilomètres or 48 miles per hour. On its course the mud-stream must have swelled into great waves, as in a surging current. This is attested by eye-witnesses. The wave-like traces left on the sides of the hill (Pl. VI.) show how the torrent surged upwards when it met any obstacle either obliquely or at right angles. In one case near Kawakami, the earth reached a height of at least 40 mètres above the general level on a hill facing the direction of flow and at other places a spur of the hill which the current struck obliquely caused an uprush of from 30 to 60 mètres. The general appearance of the present surface is one of extraordinary havoc and confusion, irregular lumps of earth being mixed up with torn-off trunks and branches of trees, fragments of timber, and stray boulders of huge size. In some places

the matter has been largely admixed with water, and is treacherous to walk on.

In describing the phenomena of the earth and rock *débris*, the word *mud* has been frequently used by several observers, who speak of "mud-stream," "mud-field" etc. We also have used the term above, but it must be explained, to avoid misconception, that we have done so for convenience only. Some commentators, indeed, have erroneously classed the phenomena with those of the "mud volcanoes" of which we read in geological text-books that, while some have been known to throw up mud to a great height, in others liquid earth only oozes out quietly, and gradually forms an earth-ring round the crater. Such outbursts, however, are no more than moderate manifestations of subterranean energy, and are almost insignificant in comparison with the tremendous forces that destroyed Kobandai-san. Moreover, as far as our prolonged examinations went, there was no evidence of any discharge of mud from beneath. It is true that in the Nagase valley and other places there are now immense quantities of mud, but these became mud only after the eruption. During its descent, for example, a part of the *débris*, mingling with the waters of ponds and lakes in its course, doubtless acquired a muddy character and was thus assisted in its flow; and, again, that which reached the stream of the Nagase-gawa became admixed with sufficient water to thin it to the consistency of a paste. But by far the greater volume was comparatively in a dry state, being moistened only by condensing steam, and must have derived its fluid or semi-fluid properties from a rapid process of pulverization after the manner already described.

With regard to the secondary mud-stream that ran down to Miné, there has been a diversity of opinion. Some visitors imagined that there must have been more than one crater—that, in fact, the materials which destroyed Miné had a separate origin from the rest; and a cleft or depression at Hikage

in Biwa-sawa, which, as viewed from below, bore some resemblance to a broken crater-wall, was not unnaturally regarded as a proof of this assumption. But the spot, when examined by us, was found to be wanting as well in the characteristic feature of a crater as in any appearance of its having been the origin of a violent volcanic outburst. If there had been such an outburst as to produce the vast quantity of matter that descended towards Miné we must have seen the crater or cavity from which the matter issued, unless indeed it were supposed to have oozed forth gradually after the manner of some of the mud-volcanoes already spoken of—a supposition, however, which is absolutely at variance with the observed facts.

The matter which descended toward Miné was really found, upon close examination, to be the loose red loamy soil that had formed the superficial covering of the flanks of Bandai, largely admixed with ash or dust, and boulders. The red colour of the soil was, however, concealed from view by the coating of grey-coloured "ashes," 10-30 cm. in thickness, that fell especially abundantly down Biwa-sawa, the wind having been directed straight into that ravine during the eruption. At Numano-taira the accumulation of ashes was especially thick, and from thence it gradually lessened toward the lower part of Biwa-sawa. The mud field of Miné examined some time after was found to have been cut by the action of running water into numerous deep chasms often forming perpendicular walls and exposing the red loam underneath.

Among the various phenomena that constantly bewilder the eyes of visitors to the scene of the eruption, not the least striking are the numerous big boulders, some of them measuring from 5 metres to 10 metres each way, that are to be seen resting on the surface of the *débris* far away from the crater. These have evidently been carried along as part of the mud current, and not hurled through the air. Not less curious are the quantities of small cones, varying from a few metres up to 15 metres in height, which are scattered here and there over

the surface, standing out of the *débris* like so many miniature Fujiyamas. Fig. 1, Pl. VII. and Pl. VIII will give some idea of these objects, as seen respectively from the northern and eastern side of Bandai. When closely examined, they are found to be disintegrated crumbling rocks, so affected by the agency of heated steam and corroding gases as to have lost their compactness. They are similar in character to the disintegrated rock commonly found near the crater-walls of active volcanoes. During and after their swift descent down the mountain sides, these rock masses have crumbled away, and the *débris*, falling around their bases, has assumed a conical shape by forming *taluses* around them. Fig. 2, Pl. IV, is a representation of one of the smaller of these hills found near the former site of the Kawakami spa.

On reaching the outposts of the mud field, no one could help being struck by the singular way in which the advancing stream of rock and earth seemed to have suddenly stopped, showing a vertical or nearly vertical face, a few metres high. It is apparent that the *débris* of rock and earth in their swift descent behaved like a fluid, but on nearing to the plain below they gradually lost speed and were ultimately brought to rest; the materials that followed, on account of their great friction and adhesion could not pass the limit set by their predecessors, and were piled layer on layer, thus forming a steep edge.

As is usual in all volcanic outbursts, large quantities of greyish-blue dust, or so-called ashes, fell during the eruption in the form of showers. Evidently much of this dust was produced by the mechanical trituration, during their flight through the air of the rocks ejected by the explosions, which rocks, as already explained, had been rendered highly friable by the action of steam and gases. We found, in fact, that the dust was allied in character to the pulverulent matters composing the conical heaps of *débris* above described, and that both were derived from the andesitic rock which composed the mass of Bandai-san. Hence it is apparent that this dust

a. Cryptomeria. *b*. Pine.

or ash is quite different in character from the ashes that are usually ejected from craters in other volcanic eruptions, *e.g.*, that of Krakatoa in 1883. In such cases, the ashes are chiefly derived from molten magma, expelled by steam and mixed with fragments of the pre-existing rocks. They contain, therefore, more or less glassy matter, and are in fact pumiceous.

On the morning of the 15th, the wind blew from the W.N.W., so that the dust was carried towards the E.S.E., gradually spreading as it receded from the mountain. On the coast of the Pacific Ocean, which is 100 kilometres or 62 miles from the volcano, the width of the dust-fall was 50 kilometres or 31 miles. In shape the dust-strewn area resembled that of partly opened fan, as shown by the dotted space on Pl. X. On the land it covered a space of about 2,050 square kilometres or 790 square miles. How much farther it spread over the ocean we had no means of ascertaining.

At the immediate foot of the mountain, specially toward the S.E., the dense cloud of dust produced pitchy darkness, which, however, did not last long; in the course of an hour the gloom had diminished to about that of the twilight of a rainy evening. But it was nearly 4 o'clock in the afternoon, or 8 hours after the eruption, before the dust wholly ceased to fall. The thickness of the deposit was about 0.3 mètre on the south and and east flanks of Biwasawa. In part the fall was in the form of a sticky, scalding mud-rain, produced by commingling of the dust with condensing steam. It inflicted terrible burns upon people exposed to it, and was the cause of many deaths. The ground also became so hot from this rain and the later dust that people had great difficulty in walking upon it. Every object was covered with a thick grey coating. Foliage, especially, that of the *sugi* (*Cryptomeria japonica*), presented a very curious appearance, the leaves, branches, &c., being clothed with a thick, pasty, and highly tenacious deposit resulting from a mixture of dust with condensing vapour. In Shibutani and its neighbourhood, which experienced the full effect of the

dust-fall, not a green thing could afterwards be seen. Houses, paths, trees, fields, in fact all visible objects—wore a greyish hue. At Miharu, a town 38 kilometres (24 miles) east of the volcano, the dust began to fall at about 9 a.m. and lasted till 2 p.m. During this period the sky had a dim and cloudy appearance, as on a misty day. The ashes hardly covered the ground, but all the leaves of trees and vegetables were tinted grey. At the coast a very slight film only was perceivable on the house-roofs and foliage. Damage to plants and crops by the fall of dust extended as far as 10 kilometres from Bandaisan.

The explosions were accompanied by terrible wind blasts, or *coups de vent.* In the parts most exposed to the fury of these blasts, houses were levelled to the ground and trees torn up by their roots. Everywhere, however, as might be expected, the fall was in a direction radially away from the forces of explosion, which was also the origin of these destructive and fearful gusts. In Pl. I. the area swept by the windblasts is shown by arrows, their heads pointing in the directions in which the trees and other objects fell. It was curious to see the manner in which one particular field of growing rice, on the south-east of the volcano, had been thus levelled by the wind. The slender stalks were laid flat upon the ground as evenly and regularly as if they had been combed down in parallel lines. Not a stalk lay across its neighbours. The heads of rice in one furrow covered the roots in the next furrow, and the entire field look like the warp of some huge loom ready for the weaver's hands.

It would appear that the tremendous explosions of steam at quick intervals, lasting for about a minute, produced violent disturbances of the air, consequent upon the sudden radial expansion of the liberated volumes of steam. When a large piece of ordnance is fired, grasses, shrubs, and objects in the vicinity are overthrown by the sudden expansion of the gaseous products escaping at the muzzle, which, displacing the air,

imparts to it a forward impulse and violent vibratory motion. The eruption of Bandai-san may be aptly compared to the firing of a tremendous gun—such an one, however, as can only be forged by Nature.

Places screened by hills and mountain side escaped. Marumori-yama, situated near the mouth of the crater, and fully exposed, received the severest damage. This hill, which was formerly covered with a thick forest, now presents a most melancholy appearance, the few trees left standing being as naked as telegraphic poles. The levelling of houses and shattering of forests are of common occurrence in great storms. But on this occasion the destroying tempests especially near the crater were something more than atmospheric, consisting besides of heated blasts of steam and air, thickly mixed with dust and rock-fragments fierce enough to crush the trees and to strip them not only of branches but even of their bark, and withering, scoring, and scorching everything in their course.

Some of the most terrible effects of these tornadoes were wrought in the Biwa-sawa and its vicinity. Originating at the old crater, Numano-taira, this glen, the deepest and widest in Bandai-san, descends directly and in an unbroken line to the villages Shibutani and Sirakijō. Notwithstanding the comparatively great distance of these two villages from the crater, the wind-blasts were impelled towards them, down the Biwa-sawa, with prodigious force, and wrought havoc from which places a little out of the direct course of the wind were happily exempt. In the woods on the S.E. slope of Akahani-yama and on the west side of Biwa-sawa, the effects of the storm were especially striking; trees with a diameter of more than a a metre had been laid prostrate on the ground in thousands; and a forest was thickly encumbered with fallen trees. Estimating the probable velocity of the wind from the effects produced in this locality, Mr. Y. Wada, of the Imperial Meteorological Observatory, thinks it can hardly have been less than 40 metres per second, or about 90 miles per hour. Here, as

the expanding steam and the rush of air, and saved the forests behind. But on the north, there being no obstruction in that quarter, to which moreover the discharges were directed at an inclination to the vertical, the effects were probably tremendous, as was evidenced by the condition of Marumori-yama. Indeed, every spot of the ground to the north of the crater, for several kilometres, was utterly turned 'topsy-turvy' and every landmark obliterated. For this reason it was impossible to tell the real state of things in that quarter.

It is well known that at volcanic outbursts the immense volumes of steam suddenly expanding occupy a much larger space than that of the original bulk. This sudden expansion cools the temperature of the surrounding atmosphere and lowers its pressure. Moreover, the steam in part condenses. To fill the partial vacuum thus produced, and to equilibrate the reduced pressure, there follows an inward rush of air towards the crater. The strong winds commonly described as a feature of volcanic eruptions, are probably due to this cause, and the same thing doubtless happened to a certain extent in the case under discussion. Bnt the fearful blasts that wrought such havoc in the forests and villages on 15th of July certainly were not counter currents of this class, however strong these may have been. It was the gusts *from* the volcano that in this instance wrought the real havoc.

A whirlwind is described as having occurred during the volcanic eruption* in the Island of Sumbawa, in Java, on the 5th of April, 1815, when, soon after the ashes began to fall, a violent whirlwind ensued, which blew down nearly every house of Sangir; it tore up by the roots the largest trees, carrying them into the air, together with men, horses, cattle, and whatsoever came within its influence. The whirlwind lasted about an hour. It is not stated in this account, however, how the whirlwind was caused.

Several visitors to Bandai, ascending from the south sides

*Lyell's Principles of Geology, 12th Ed. Vol. II., p. 104.

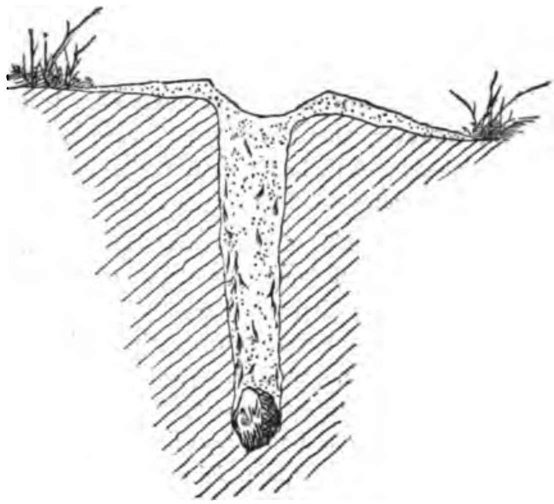
and approaching the summit, had their attention attracted by numbers of curious conical basin-like holes, evidently the fruits of the late eruption. Their size varied from .2 to 3 metres in diameter and from a few decimetres to more than a metre in depth; and they were generally wider at the mouth than at the bottom. They were found in thousands in the neighbourhood of the crater, as well as on the extensive slopes of Ōbandai and Akahani, a few kilometres away.

As to the origin of these holes, though they were not perhaps a very important phenomenon of the eruption, it calls for a brief discussion, because it has been the subject which has caused a good deal of diversity of opinion and some lively controversy. First of all, they were regarded by some witnesses as miniature craters, each formed by a small explosion of steam. This supposition arose from the fact that several of the holes had the appearance of having been formed by ejections from below the surface, and that in some cases steam had been seen issuing from the holes. But the latter phenomenon was only to be seen near the solfatara adjoining the new crater, from which steam had been issuing for ages; and the appearance of fresh steam-jets in that locality would not be surprising after the convulsions caused by the catastrophe of the 15th of July. Even, however, if it be allowed that there were a few slight steam explosions in this immediate vicinity, it is, in our opinion, impossible to extend any such hypothesis to the innumerable holes of like appearance that were scattered over the extensive and distant slopes of Ōbandai, Akahani, &c. Prof. J. Milne, on the other hand, regarded the cause of the holes as seismic, but not volcanic, that is to say, he concluded that earthquake-waves produced at the time of the eruptions, and passing through the soil, caused sub-surface compression and distortion and thereby ejected earthy matter from below, by the spouting action of water. We shall show farther on that the above theory can hardly be applied to any but a few marshy spots in Numano-taira to be presently described.

Others, again, contend that the holes were caused by the fall of stones projected into the air from the crater. This we take to be the true explanation. Puzzled at first as to the origin of the holes, but determined to investigate it fully, we dug a number of them open. Thereby our doubts were soon cleared up. We found embedded in the ground brittle and freshly fractured stones that had apparently been shot forth by the volcanic outburst. Where the soil was rocky, fragments of similar stones were scattered all about. In one case we obtained very decisive evidence. A stone was discovered in soft loamy soil formed by the decomposition of andesitic rocks, at a depth of nearly 2.5 metres below the surface. The stone was angular in shape, measuring nearly 0.5 metres each way, and showed a freshly broken surface. Leaves of bamboo, dwarf pine, and creeping surface plants had been carried with it into the soil. These were much packed and crushed, but were still fresh and green when dug out. On closely examining the hole we found that, although more or less funnel shaped near the surface, it had been sharply cut through in a tubular form, by the passage of the stone which lay at its bottom. The original tubular passage was, however, filled up by the loose detritus mixed up with ashes, and here and there with shrubs and bamboo twigs, while the surrounding soil was a compact native red loam. The main features of this hole are shown in the diagram on the opposite page.

It was stated before that the steam ascended perhaps 1,280 metres (4,200 ft.) above the crater. If stones were thrown up to the same height as the steam column, their initial velocity must have been 158 metres per second, and this may be roughly taken as the final velocity with which, on falling down, they would reach the ground. But if we suppose that the steam and stones reached to double or treble the above height, which is not improbable, the initial velocity becomes 224 and 274 metres per second respectively. The velocity needed for penetrating a soft loamy soil to a depth of 2.5 metres would

be between 300 metres and 900 metres per second, according to the values of coefficients we take, but in these calculations, as we are using several more or less arbitrary assumptions, we cannot take them as a sound basis for discussion.



It seems not strange, however, to find that the basin-like holes wearing those appearances of having been blown out from below have led to the theory of their formation by internal explosion. Stones striking the grouud with great force would make holes of larger diameters than their own by throwing the surrounding earth outward. Again, if the fall of any stone take place at a spot where there are rocks on or near the surface of the graund, the concussion will shatter the falling stone and at the same time blow up the adjoining soil, thus producing the appearance of an eruption. We have witnessed great number of those cases on Ōbandai and Marumori-yama.

The inhabitants at the base of the mountain noticed among the rising steam small and large white objects ascending and descending like shooting stars. At one time, they were so

numerous that they almost looked like white rain. It seems very probable that these objects were stones ejected from the crater.

That large fragments of rocks are hurled into the air during volcanic eruptions is a matter of common experience. But that they have left their traces upon mountain sides in the form of conical holes has not, as far as we know, been recorded; perhaps it has never been observed. It must not be forgotten, however, that there would have been no such holes on Bandai-san if there had not been the thick layer of soft loamy soil to receive the falling rocks.

Mr. E. Odlum, of the Toyō Eiwa Gakko (Oriental English School), Tokyō, made a thorough investigation of the conical holes. He went twice to Bandai, the second time for the sole purpose of examining the holes, and his observations on the spot were very complete. Indeed, we consider that the facts and proofs brought forward by this observer must be held to settle the question. In a paper read last autumn before the Seismological Society of Japan, Mr. Odlum showed that hundreds of thousand of stones had been hurled into the air from the crater. People were wounded and forests were shattered by them. Sometimes fragments of rocks of considerable size were imprisoned on broken trunks of trees. Native mountain rocks had on their upper surface marks and scars made by the stone projectiles. On excavating some of the holes, Mr. Odlum found in them embedded stones, some of which weighed 4,000 lbs. or 1,814 kilogrammes. Under these grasses, weeds, leaves, branches, and other kinds of vegetable materials were sometimes discovered, often bruised and shattered till they had the appearance of having passed between rollers. Many of the stones fell in a slanting direction; they were not lodged in the centres of holes, but almost always to one side, that is, the side away from the crater. The earth round the embedded stones was solid and native—no sign of their having been disturbed by explosive

action or the like was found. The whole mountain, the top as well as valleys, was covered with these pits as if it had had a heavy attack of small-pox. To suppose, continues Mr. Odlum, that the holes were formed by the spouting action of subterranean water, as is held by some authorities, we must assume that the whole mountain was literally made up of water, and inundation must certainly have resulted from the creation of such immense number of water jets in a short space of time. Mr. Odlum made numerous measurements of the pits; they vary from a few feet in diameter to over thirty feet, and from 2 to 10 feet in depth.

Lieut. Y. Nakashima, of the Army Department, who surveyed the volcano after the eruption, and who, from the nature of his work, acquired an intimate knowledge of the whole area, is in entire accord with our opinion as to the origin of the pits.

Notwithstanding these evidences, however, the conclusions arrived at by us and other workers have been freely criticized, and doubts have been thrown upon them. Prof. J. Milne of the Imperial University, dissenting from our views and those of Mr. Odlum, believes that the cause producing the holes was seismic in character—to wit, the severe earthquake that accompanied the eruption. He quotes Robert Mallet in support of the hypothesis that they were produced by the spouting action of water from beneath, resulting from seismic compression of the substance of the ground. Similar pits, he says, were made in the great Calabrian earthquake of 1783, and they were specially investigated by a committee sent from the Royal Academy of Naples. These gentlemen also dug into holes, Prof. Milne continued to say, but we do not hear of their having found any boulders. We (the authors of the paper) think that the Neapolitan scientists did not strike into boulders, simply because the pits in the Calabrian plain were not formed by falling stones, which was the case on the slopes of Bandai. It was also argued that like phenomena were observed in the

was felt in the Bandai-san district its origin was far away to the west near the coast of the Japan Sea.

On the morning of the 15th, at a little after 7, a feeble earthquake occurred, but it was so slight that many failed to notice it. After half-past seven a severer shock ensued, lasting nearly 20 seconds. This was followed soon after by very violent convulsions of the ground; houses rocked and swayed, furniture fell down, and the frightened people felt the ground heaving beneath their feet. It was reported that the nature of this earthquake differed from that usually experienced, in that vertical motions greatly predominated. The shock was a long one, lasting, according to some accounts, for fully a minute. While it was still in progress the eruption took place. Considering the fierceness with which this earthquake shook the immediate vicinity of the mountain, it is remarkable that the intensity was very rapidly decreased as the seismic waves were propagated into the surrounding region, and the shaken area was limited to a radius of, roughly speaking, about 48 kilometres, or 30 miles. This may be accounted for by the fact that the origin of the shock was rather near the surface. On Pl. X. the boundary of the the area shaken by the earthquake is shown by a thick elliptical line.

Volcanic eruptions are generally accompanied by earthquakes, and the shocks on this occasion prove that sudden expansion of steam and breaking up of the earth's crust may produce seismic vibrations. The efforts of the pent-up steam struggling to force its way through the superincumbent masses, at last succeeded in bursting through a weak point, the explosion being accompanied by violent convulsions of the ground that were propagated as seismic waves.

On the 20th of July, at 11.50 a.m., a feeble shock was experienced. Other minor shocks are said to have subsequently occurred.

To see whether the ground in the crater was perfectly quiet after the eruption, we took with us a delicate though somewhat

roughly made pendulum tromometer, which had a magnifying power of 27. We first set it near a fissure from which powerful jets of steam were issuing with hissing sounds. In that position the instrument indicated very feeble vibrations of the ground, which were doubtless caused by the issuing jets. We next set it in Nakanoyu, near our camp, and made daily observations. As far, however, as the magnifying power of the instrument enabled us to judge, there was no evidence of lingering earth-tremors. And it would seem from this that the forces which produced the explosion had been completely expended in blowing away the mountain, and that the region had already become seismically quiescent.

Near the volcano the detonations in the earlier part of the eruption were described as deafening. Though rapidly lessening in intensity, the thundering noises lasted for nearly an hour, and did not entirely cease for several hours. The area over which the sound extended was very much smaller than might have been expected. From the tabulated reports at the end of this paper, and from other sources, it appears that the sounds of the explosions were not heard distinctly at a greater distance than 48 kilometres or 30 miles to windward of Bandai-san, though to leeward they were audible at the Pacific coast, a distance of 100 kilometres or 62 miles. How much farther they reached, over the sea, we had no means of ascertaining. Mr. K. Nakashima, of the Geological Survey, told us that, while he was ascending Kinboku-san, in the island of Sado, on the morning of July 15th, he heard dull rumblings which were supposed at the time to proceed from the firing of heavy guns in the neighbouring harbour (Report 21). Sado is in the Japan Sea, nearly 161 kilometres or 100 miles west from Bandai-san, and therefore to windward of it. Possibly, however, the sounds heard by Mr. Nakashima came from the volcano. It was also reported that peculiar detonating sounds were heard on the same morning in Takai-kori, in the Province of Shinano,

distant about 164 kilometres or 102 miles south-west from Bandai-san. The barograph in the Imperial Meteorological Observatory in Tōkyō, which is 212 kilometres or 132 miles south of Bandai, was not affected. The magnetometer in the Observatory also gave no record that could be regarded as an effect of the eruption.

While we were staying on the mountain we often witnessed the fall of large masses of the perpendicular crater wall, which, coming down from great heights with stupendous force, were smashed into thousands of fragments and descended with whirlpool-like movements to the lower levels. These slips produced terrible rumblings, which resounded throughout the crater, and were also heard far away. By the already panic-stricken inhabitants of the neighbouring villages these repeated noises were regarded with consternation as tokens of a further volcanic outbreak, and it was weeks before they become pacified and assured as to the real cause.

From the ascending columns of steam and ashes vivid zig-zag flashes of lightning were seen to dart forth, and were accompanied by loud roars of thunder. These phenomena, observed from several points around the mountain, may be regarded as resulting from the discharges of frictional electricity which, as is well known, are liable to be brought about in volcanic explosions when steam at high tension escapes through a narrow orifice, and collides with the surrounding air and the more solid ejectamenta.

While the main eruptions were going on, the people in Inawashiro and the neighbouring villages saw through the densely falling ashes innumerable vivid sparks of fire on the slopes of Ōbandai and Akahani, at considerable distances from the crater. These sparks were quite different in nature from lightning, presenting rather an appearance as of the firing of a vast number of guns. The probable explanation of the phenomenon is that sparks of fire were produced by stones and rocks striking against each other in the air

or falling on a rocky bed. Fragments of rocks are scattered in abundance on the slopes of Ōbandai, but we could discover nothing to lead us to believe that there had been combustion or any other heat manifestations. Sensational newspapers in their accounts of the eruption spoke of lurid flames, of a blazing crater, and other terrors all probably founded on the peasants' reports of the sparks above mentioned. It very rarely occurs, however, in volcanic eruptions that flames are produced by the burning of gases issuing from craters. Sir W. Hamilton, in describing the Vesuvian eruption of 1779, noted that large vitrified masses (bombs), falling upon the ground, broke into many pieces, and set fire to combustible objects. In this case, however, the fire was produced mainly by the heat of the fused masses, whereas at Bandai the sparks were caused by impact. On the other hand, at the time of the great volcanic eruption of Tarawera, New Zealand, in 1886, the falling sand was said to have been hot and to have set the trees on fire.*

As regards unusual optical phenomena, we have heard of one or two only that seem to have been connected with the eruption. Anything like the twilight-glows, haze, etc., which were such important features after the Krakatoa explosion, could hardly be looked for in this case, which, though exceedingly remarkable in many respects and interesting in the highest degree, was very much inferior in magnitude to the gigantic eruption of 1883 in the Sunda Strait. However, an observer at a place about 87 kilometres or 54 miles S.E. from Bandai noticed towards evening on the day of the eruption sparkling rays of red light issuing from the clouds (Report 14). Another, living in a village S.S.E. of the mountain, saw with mixed fear and delight how the rising columns of steam from Bandai-san, refracting and decomposing the light that fell upon them, produced a most beautiful display of variegated colours (Report 8).

* Nature, Vol. 34, 1888, p. 392.

It has been often asked whether there were any premonitory signs of the explosion. It is certain that slight shocks were felt on previous days, as well as half an hour before the outburst. But beyond this the evidence is vague. Some persons vouch to having heard mysterious rumbling sounds in the mountain prior to the eruption. Again, some animals are said to have shown alarm. No doubt before an explosion of such magnitude as that of Bandai-san, earth must have been in a seismically sensitive condition, and certain animals which are known to be highly susceptible to even minute earth-tremors may very well have been frightened on this occasion. Some well-waters are also said to have diminished in flow. None of these alleged facts, however, have been clearly established on the evidence of trustworthy persons. On the other hand, Mr. Tsurumaki says in his letter (see above) that the bathers at Nakanoyu did not observe any abnormal changes in that spring, though it is situated on the very edge of the new crater. It would be interesting to know exactly how Lake Inawashiro behaved before the eruption. The water level of that lake is systematically recorded at two places on the shore, for purposes of irrigation. But we were unable to learn, either from conversation with Mr. Akiyama, who keeps the record, or from the entries in his books, that there had been any sudden fluctuations of level during the two months preceding the catastrophe. In reports lodged at the Fukushima Prefecture it is stated that the river Nagase, the lake's chief feeder, decreased its flow from April or May, and that the water level of the lake on the 1st of July was one foot lower than on the corresponding day of the previous year. A captain of a steamboat running on the lake told us that his vessel, anchored close to the shore, was moved outwards nearly 0·6 metres by the disturbance of the water. Though this disturbance occurred almost simultaneously with the eruption, we are disposed to agree with the captain in believing that it was a result of the earthquake immediately preceding it.

On the whole, the only premonitory signs that were really trustworthy were the slight shocks which occurred on previous days and half an hour before the eruption, and no implicit faith can be placed on the slight testimony in favour of other warning symptoms.

Volcanoes have often been described as one of the principal restorative agents in counteracting the denuding action of water that tends to bring the surface of the earth to a level. In the late eruption of Bandai, however, the effect was destructive and not constructive. The materials which had accumulated in past ages gave way, and were thrown down from a higher to a lower level in less than an hour; the effect of this being analogous to a gigantic land-slip. In this way, considerable changes have been wrought in the topography and contour of the adjoining districts. How the torrent of earth and rocks devastated an area of some 70 square kilometres (27 square miles) has already been described in the preceding pages. The general effect of this spreading out of *débris* was to effect the levelling of the general contour; all the surface, ravines, and gorges, being entirely filled up. The northern side of Bandai was, before the eruption, an undulating grassy plain—the "Hara" so characteristic of volcanic districts in Japan—drained by the river Nagase, and dotted here and there with some straggling hamlets. Professor J. Milne, who visited this part of the country several years ago, described it as consisting of grassy slopes without any exposure of rocks. The descending deluge of *débris* pouring across Ōbudaira, as the northern slopes of Kobandai are called, engulfed all the familiar land-marks, and converted the district into a desert waste. Thousands of conical mounds, large and small, have been formed on this vast sea of mud, giving a quite unique appearance. Not only have the depressions been filled up, but the higher ridges have been reduced in height. The deluge of earth *débris* in its quick descent, impinging on the prominences that were lying in its way, have actually leaped over them, scraping off the

outer crust of the soil, and exposing the native rocks beneath, as a glacier might have done. In other places the torrent of rocks dashed against the hill-sides and scoured them away. Large quantities of mud carried along with rocks, *débris*, and boulders, have penetrated deep into every recess of the valley. The largest and longest of the mud streams is that which flowed down the slope of the river Nagase to the Kawakami spa. Near the village of Hibara, and the former site of the little hamlet of Hosono, the peaty deposits which had accumulated in the marshy ground have been ploughed up. Large clumps of red loamy soil mixed up with half carbonized wood and grasses are turned up or standing in an irregular state of contortion.* Nowhere could the scouring action of the mud torrent be better realized than in these parts.

The official reports relating to the area of land buried under mud are given in the following figures. The loss of property involved is said to have been immensely great. There is absolutely no hope of recovering or reclaiming the buried land.

	SQUARE KILOMETRES.	SQUARE MILES.
Cultivated land	0.82	0.32
Plains	22.60	8.73
Mountains and forests	41.93	16.19
Rocky slopes and glens	5.36	2.07
Total	70.71	27.31

It is highly probable that, though at present the new land appears like a desert waste, the growth of vegetation will take place in a comparatively short time favoured by the admixture of the fertile volcanic products.

One of the most striking secondary effects of the eruption

* Among this turned up peaty deposit, an interesting occurrence of *vivianite* may here be noticed. The formation of this mineral seems to have been brought about through the agency of organic matter. It is found in the form of a beautiful azure-blue coloured, fine powder, filling up the spaces especially of the rind and core of the fragmentary branches of half carbonized wood belonging to some Coniferous tree. The spot, however, where we have witnessed this phenomenon, being situated just on the southern front of Hibara lake, must have now been submerged under water.

is the formation of new lakes, due to the damming up of the river Nagase and its tributaries by the *débris* of the shattered mountain. These lakes are four in number, and are shown on Plate I. They may be conveniently called Osuzawa, Hibara, Onogawa, and Nakatsu (or Akimoto) lakes, after the tributaries of the Nagase to which they are respectively due. The largest of them is Hibara lake, measuring nearly 4 kilometres or 2.5 miles from north to south, the breadth being nearly $\frac{1}{3}$ of the length. These lakes continued for many months to increase in size, through the gradual accumulation of water within the newly formed barriers of *débris*. Thus it was not till fifteen days after the eruption that the village of Onogawa became covered with water. The inhabitants then fled to Hibara, but were subsequently driven out from that village also as the waters gradually rose.

Beside these four large lakes, there are scattered among the mudfield smaller patches of water caused by the accumulation of rain water, or formed by the smaller streams on the mountain-sides. These lakes will continue to increase in size until the water comes to the level of the lowest possible outlet from the hemmed-in basin. The issuing stream will soon cut deep passages through the loosely cohering *débris*; and it is to be expected that sudden yieldings of some of the barriers will take place. Hence will result a rush of escaping water accompanied by violent floodings in the lower courses of the stream. It was thus that certain villages and cultivated fields were flooded when the Nagase-gawa burst its lowest barrier, which immediately after the eruption quite stopped the flow of that river into Lake Inawashiro. Because of the loosely compact character of the *débris*, the configuration, size, and number of these lakes will alter greatly as time goes on.*

* As this is passing through the press, we are able through the kindness of Professors C. G. Knott and C. Michie Smith to call attention to the remarkable changes in the region under consideration. These gentlemen visited Bandai towards the end of May, 1889. They report that Hibara and Osuzawa lakes have united into one huge lake which forms the most prominent feature in the landscape. The other

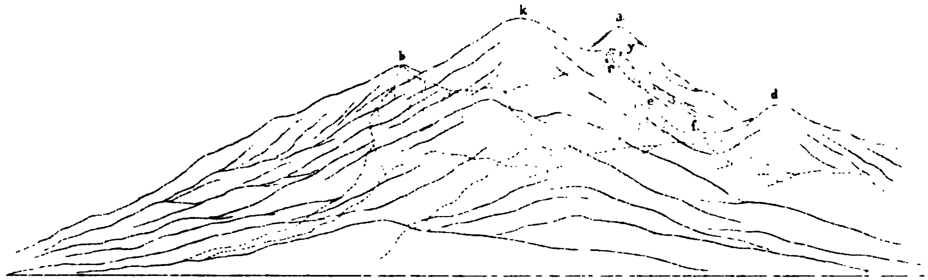
On the 13th of April of this year (1889) about 6 p.m., a large portion of Onogawa lake was suddenly drained, and the torrent of water rushed through the mud-field, carrying mud, pebbles, and boulders to the lower levels. The embankment newly erected at Nagasaka and other places to protect from inundation, was destroyed, and the water spread out into the cultivated fields adjoining the district of Inawashiro. Considerable damage was done to bridges, and roads, but fortunately the houses and inhabitants escaped.

New lakes or ponds are also being formed within the crater, by the condensing steam and the rain water. The waters of these lakes contain much soluble matters and some of them are hot. But as the crater-bottom is set in a sloping position, an accumulation of water to any considerable extent cannot take place.

The distant view of Bandai as seen from certain directions has been altered by the destruction of Kobandai. When viewed from its south side, however, *e.g.*, from the town of Wakamatsu, the mountain apparently does not show any sign of great change; the prominent peak of Obandai entirely screening from view the place of devastation. Before the time of the explosion, the top of Kobandai, when seen from this side, was presented as a small prominence on the left side of Obandai. Fig. 3, Pl. VII., is a sketch taken soon after the catastrophe. The dotted outline in this figure is the original form of Kobandai, which has now entirely vanished, and in its place columns of steam are seen rising.

The most magnificent sight is presented to view when the mountain is seen from the northern side, where the full force of the explosion may be best realized. The newly opened

lakes are comparatively small. Of particular interest, also, are their observations on the erosion of the new earth by the action of running water. Thus the comparatively small stream that ran down Biwasawa has cut out of the new earth a deep V-shaped gorge, in many places attaining a depth of 40 or 60 meters. At these places the stream has not yet cut down to the original surface. See their paper, following this one.



Cut showing probable form of mountain before the eruption.

explosion-crater (Fig. 1, Pl. II., Fig. 1, Pl. VII.) is fully disclosed, the wreath of steam rising from its central linear fissures like a cumulus cloud. The sound of the evolving steam is distinctly heard from the village of Hibara fully 9 kilometres distant, evidently due to the fact that the crater opens unobstructed on this side, and is backed by perpendicular walls. On the right side we see a jagged rocky precipice, the remains of Yugeta-yama which formed a small prominence on the flank of Kobandai. The extensive waste of mud and rocks, gradually sloping from the crater toward the plain below with its curious conical rock-hills and bared mountain sides, gives a most vivid and awful impression to the mind of the vastness of the devastation.

It would have been very interesting to compare the original form of the mountain as seen from the north with its present form. But as we have already stated this part of Bandai was very scantily peopled, and hardly ever visited by scientists, so that there seems to exist no sketch or photograph showing an accurate outline of Kobandai before the explosion.

The accompanying figure shows the probable appearance of the mountain previous to the eruption, this reconstruction of the original scenery being made from the sayings of the people who knew the mountain well, and from general topographical considerations. The dotted line in the figure is the present outline of the mountain, viz., the reproduction of the outline as shown in Fig. 1., Pl. VII., reduced to one half.

The prominent peak (*k*) is intended to be the restored form of Kobandai or Little Bandai, which when seen from this side must have looked more massive and prominent than Obandai, or Great Bandai (*a*). To the west of Kobandai immediately over Kamino-yu (*e*), is seen a small prominence known as Yugeta-yama (*y*), which was half destroyed, forming now a very rugged precipice as already mentioned. It is to be observed that the fumarole of Kamino-yu is situated

within a small ravine having a very steep side-wall, probably itself a small explosion-crater formed at some former period.

Four hamlets—Osuzawa, Hosono, Akimoto, and Kawakami—have been completely buried beneath the rock and mud along with their inhabitants and cattle, leaving no visible trace of their former existence. Even the few survivors who escaped death by their timely absence from home could not tell where their villages had been, as every land mark was entirely obliterated. Seven villages—Miné, Nagasaka, Shibutani, Shirakijō, Hinokuchi, Myōke, and Ojigakura—were partially destroyed either by the avalanche of earth or by the storm of wind and rubbish, and were thickly covered by ashes. The loss of life and cattle was also considerable. The destruction of the three spas in Bandai-san, viz., Kaminoyu, Nakanoyu, and Shimonoyu, has already been mentioned. In all, 166 houses were either totally or partially destroyed.

The total number of lives lost amounted to 461. The principal cause of the death was the deluge of rock and mud *débris*. In some instances people were buried under their roofs, having no time to escape; but in the majority of cases they were caught in the swift torrent of mud while endeavouring to reach some safe place. Many were also battered by falling stones. A most remarkable incident occurred in the village of Nagasaka which had 168 inhabitants, and was attended with a serious loss of life. This village being situated behind Kushigamine was effectually screened from the direct attack of the mud current. On the morning of the eruption when stones and earth began to fall upon their roofs, accompanied by appalling noises and earthquakes, men and women rushed out of their houses leaving the old and young behind, and attempted to cross the valley of Nagase in order to reach the opposite hill which they thought to be a safer situation. They had only to travel not more than 500 metres across, but of ninety-two thus fled, not even one reached other side safely.

Out of the total of 461, only 117 corpses were recovered, all

the remaining bodies being entirely buried under the mud. The number of wounded was 70 in all. They were mostly burnt and scarred by the hurricane of hot ashes and falling stones. The wounds in several cases were very peculiar. Fragments of rock projected violently from the mountain, impinged upon the unfortunate people like grape-shot. The sufferers were tossed about and often felt as if they were lifted up bodily into the air; at the same time their clothing was torn off, even to the under-garments. In many cases bits of stones were found sticking in the skin and flesh of the victims, and were with difficulty extracted. In one case the skin was completely peeled off from a woman's skull, probably torn through entanglement with trees or other objects which were being violently hurled along. The mere contemplation of such experiences is horrifying.

Bandai-san after the Eruption.

The winter climate of this part of the country is very severe. Snow begins to fall in the middle of autumn, so that in winter travellers are rarely seen, and the peasantry hardly ever venture far abroad. The result is that very little knowledge can be obtained about the behaviour of the volcano during the cold months. Mr. S. Kobayashi, a school-master at Inawashiro, who helped us in various ways during our stay in Bandai-san, has, at our request, very kindly given us the following information :—

Letter dated Nov. 7th, 1888.—Since the eruption, even in bright and calm days clouds have been almost always seen round the summit. This has not been so in former years.

This is very probable. The steam that issues from the crater, in ascending and dispersing in the higher region, would produce cloud.

Nov. 8th.—The volume of steam has abnormally increased since yesterday. It is nearly the same as it was three weeks after the eruption. This morning the amount is still greater. Although its height is perhaps not greater than that observed within ten days after the eruption, its volume does not seem to be less.

Oct. 7th.—The new lake Akimoto rushed out cutting through the mud-field, after a heavy rain-storm. In the lower course of the river Nagase, the water level suddenly rose 9 ft. above the ground, causing great uneasiness among the people.

Oct. 20th, 6h. 32 min. 3 sec. a.m.—A slight shock was experienced.

Nov. 19th, oh. 25 min. a.m.—A slight shock was felt; motion horizontal, direction N.-S., duration 1 min. 30 sec. On this day snowfall was first observed on the summits of Obandai and Kushigamine.

Nov. 30th.—Thunder-claps were heard toward Bandai-san and Azuma-san, lasting about 20 minutes; have seen lightning twice.

Dec. 1st.—First snow-fall on the ground.

Dec. 5th.—Sound of distant thunder heard.

Dec. 30th.—Great storm swept the accumulating snow over Bandai, and with it the ashes on the mountain-flank. Peculiar rumbling noises heard in the mountain. People believing this to be a sign of a fresh outhurst of Bandai were very much frightened.

Jan. 1st (1889).—A slight shock was experienced at 7h. 10 min. p.m., lasting 2 seconds.

Jan 23rd.—A *halo* observed, probably due to the refrigeration of the vapours of the steam from Bandai.

Feb. 8th.—Rumbling sound heard in Bandai, probably due to the falling of the crater-wall.

Feb. 17th.—Hibara village was deserted on account of the encroachment of the new lake.

Feb. 18th, 5h. 30 min. a.m.—A slight shock.

In his last communication Mr. Kobayashi says that during the winter the action of rain, water, and snow, has greatly eroded and smoothed down the rugged points, the vertical walls, and the precipitous hills in and round the crater, reducing them to much gentler inclines, and thus the grandeur and

picturesqueness of the scenes have been considerably lost. This fact was confirmed by recent visitors to Bandai-san. From this it may be expected that such a bold scene as that shown in fig. 2, Pl. VII., which is a sketch taken from the western edge of the crater just above Kaminoyu, about 20 days after the eruption, would not be long preserved.

The Character of the Eruption.

The explosion of Bandai has furnished us with an example of a volcano, long dormant, bursting with terrific force. So far as we know, the last great explosion took place more than ten centuries ago. Some minor eruptions are said to have occurred in subsequent years, but seem to have been of a local character. During the long period of rest, the original crater now known as Numano-taira, has in large measure lost its crater-like form by the disintegration of the surrounding walls. In such cases it often happens that subsequent eruptions take place at other parts of the mountain, breaking open new chasms along other lines of weakness. Such has indeed been the case with this last eruption of Bandai, the line of weakness lying to the north of the old crater, so that the mass of the mountain was thrown toward the north into the Nagase valley. There is now seen in the new crater a great fissure running N. 20° W. from the bottom of the horse-shoe nearly to its mouth. Along this fissure runs a long row of steam jets, large and small, puffing and hissing and emitting immense volumes of white watery vapour. Pl. VIII. is a distant view of the mountain from a photograph taken by Prof. W. K. Burton, nearly a week after the eruption, showing the linear arrangement of the steam-fissures. It was along this line that the eruptive power of steam rent Ko-bandai into pieces.

It is manifest that the immediate cause of the eruption was the sudden expansion of steam pent up within the mountain. Of lava or pumice there is no trace. The grey coloured ashes which form a chief product of the explosion are evidently the

powder of pre-existing rocks decomposed by the action of fumaroles, and have not been derived from fused magma.

The character of the explosion was thus comparatively simple, being to all appearance a sudden shattering of part of the mountain flank. The work of the explosion has been practically to tear off a portion of the side-wall of the old crater.

It has often been observed that the first action of some volcanic outbursts is characterized by extreme violence, large masses of superincumbent materials which have accumulated in the crater being thrown out, or the side-wall being blown away, by the expansive force of steam. This first stage of the eruption in usually followed by minor ones accompanied either by lava flows or pumice ejections. Thus the finer particles or ashes ascending into the air are different in character in the successive outbursts; those which are ejected during the first stage of the eruption consisting largely of fragmentary materials, while those of the later eruptions are found to be more or less pumiceous, a fact showing that the latter are derived from the fused matter. The explosion of Bandai, characterized by its suddenness and violence, and effected in a very short time, may be likened to the first stage of eruption. But no subsequent discharge took place, nor were any signs of further disturbance discernible.

We have already indicated that the volcanoes in the vicinity of Bandai, though classified as active, have never, within historic time, shown a true lava eruption. And this may be said to hold good for most of the active volcanoes on the Main Island. In fact, most of them, which had their climax of activity during Tertiary times, are now verging to extinction. This is due to the general and gradual abatement of volcanic force since the end of the Tertiary era. Any great geologic changes which have taken place since then, have had to do with the general rise of the land surface above the sea-level. At present the Tertiary strata, some three or four hundred mètres above the sea-level, cover a large part of the

whole area of Japan. They consist principally of tufaceous deposits, are mostly of marine origin, and are often found surrounding or even underlying the volcanoes. These volcanoes would thus seem to have attained their maximum intensity at a time when proximity to the sea greatly favoured their activity. But the subsequent gradual rising of the land surface has had the effect of shifting the volcanoes further and further from the sea-board, thus greatly mitigating their action.

The eruptions which are usually experienced in these volcanoes in modern times seem to be essentially superficial. The recent catastrophe of Bandai may indeed be taken as a grand example of this kind of volcanic manifestation and may well be called an *explosive eruption*. The great horse-shoe-like chasm opened toward the north may be called an *explosion-crater*. Its appearance from the north side presents a striking .resemblance to the deep chasms which are often characteristic of certain volcanoes, *e.g.*, the "Val del Bove" of Etna, the Caldera of Palma, &c., and at the same time suggests similarity of origin.

Perhaps it may be of interest here to refer to a volcanic outburst which occurred in Japan early last century and which seems to have strongly resembled the present Bandai eruption. It is the great lateral eruption, with took place on the south-eastern of flank Fujiyama in the 4th year of Hōyei (1707 A.D.). By this outburst a great chasm very similar in its character to that of Bandai, was opened on the mountain side. It is an explosion-crater not inferior in magnitude to the latter. Hōyei-zan is really a prominence ou the outer rim of the great chasm. It has, however, hitherto been regarded as an example of a "parasitic cone." It is to be observed that, in case of the Fuji explosion, there were produced numerous volcanic bombs, which are now found scattered all around the crater, showing that there was ascent of lava. Another striking phenomenon is the presence of a magnificent series of numerous vertical dykes

which traverse the side-wall of the crater. On the other hand, there may be seen on the perpendicular walls of the newly opened crater of Bandai, bands of volcanic strata exposed, consisting of an alternation of old lava-streams, and of agglomerates of fragmentary materials, a singular feature of these strata being the absence of any noteworthy dykes passing through them. The fact would show that since the formation of the Bandai group, the mountain has been very little attacked by the intrusion of molten magma from the interior.

Again, as we have already seen, among the products of the late eruption there is no lava. There are, however, among the *débris*, especially near to the spot where the steam-jets are issuing within the crater, some greenish coloured rock-specimens with disseminated patches of iron-pyrites, and a white coloured sintery rock having a bleached appearance, almost wholly consisting of silica as shown by the analysis given in the sequel. These materials indicate the action of fumaroles and hot springs in altering the rocks in the interior of the volcano, and in depositing mineral matter while percolating through the crevices. Among the *débris* that ran down to the north, are often found porous or scoriaceous rocks of a reddish or black colour, which some observers have referred to a molten origin. It is more than probable, however, that these rocks are the fragmentary materials which, having been ejected during the previous periods of activity in the history of the volcano, had accumulated in the form of volcanic strata, and taken their share in the building-up of the mountain. The destruction of Kobandai, which was itself a part of the side-wall of the volcano, reduced these strata to a powdery state, and scattered the scoriaceous materials imbedded in them abroad on the mud-field.

Survey of the Crater and the Volume and Weight of the Mountain destroyed.

After great volcanic eruptions, surveys have sometimes been made with the view of estimating the dimensions of the parts

blown away, or the amount of the material ejected during the outbreak. The difficulties attending these attempts are obvious, for it happens very often that the seat of the outburst is inaccessible on account of lava flows or other dangerous obstacles that beset the way.

In estimating the dimensions of the newly opened explosion-crater which was formed by the destruction of Kobandai, and in deducing therefrom the volume and the weight of the mass that was thus removed, we encountered one serious difficulty, viz., ignorance of the original topography and former contour of the mountain. An unexpected advantage was, however, derived from the fact that, since in the case of Bandai the explosion lasted a very short time and no subsequent outbreak took place, we could walk into nearly every nook and corner of the newly formed crater, and thus with comparative ease complete a survey which might otherwise would have been almost impossible. The inaccessible or dangerous parts were the fissure lines whence steam issued with great violence, the gorges filled with water (new lakes), and the regions at the base of vertical cliffs down which earth and rocks, and even slabs measuring one or two hundred metres, were constantly thundering. Otherwise the conditions were as favourable as could reasonably be expected in the circumstances. Not that the inside of the crater was anything like a level plain. Far from it; it was cut up by precipitous hills, deep chasms, and wild depressions of all imaginable shapes and sizes. Pl. V. shows a prominent rock-hill inside the crater, on which was located one of our stations. The crater-bed was full of these boulder-mounds, and was so irregular that we spent nearly two days in fixing upon a suitable base-line. We were, however, fortunate in finding a nearly straight narrow band in the bottom of a valley in which to locate the base-line.

For five successive days Mr. I. Toya laboured indefatigably, until all the important points were measured from prominent heights in and round the crater. When this done, we removed

to Ottate, a spa on the southfl ank of Ōbandai, and mapped the results of the triangulation.

The form of the crater, as deduced from the plan, is semi-elliptical, or like a horse-shore. It is open toward the north, its bed gently inclining outwards. The plan in Pl. IX shows the general outline. It is surrounded by precipitous walls and steep cliffs of great height, especially on the southern side, where a part of Kobandai still remains with rugged edges, and where Kushigamine exposes a clean section. The heights of the wall as may be seen from the numbers indicated on the plain gradually become smaller as we approach toward the mouth, at last reaching to the same level as the crater-bed. The heights in and round the crater were measured by taking altitude angles and were afterward referred to sea-level. The position of the steam fissure running N. 20° W. is marked with star-like signs; prominent hills, depressions, valleys, ponds, etc., are also indicated.

Roughly speaking the crater measures 2,463 metres or 8,080 feet across its mouth, which is the widest part from east to west. From the bottom of the horse-shoe to its mouth it is 2,274 metres or 7,460 feet. The total area of the crater-bed is 3·83 square kilometres or 946 acres, or nearly 1·5 square miles.

In the estimation of the volume and the weight of the mass blown away the chief difficulty encountered was our ignorance of the original contour. The original height of Kobandai, or Little Bandai, was assumed to be equal to that of Ōbandai, or Great Bandai (1,840* metres or 6,037 feet). It was generally believed that Kobandai was a little lower than Ōbandai, probably owing to the fact that the former was situated further away from the more populous districts in the vicinity and was partly screened by the latter. We were told, however, by those

* From barometric measurements by Messrs. Y. Wada and N. Ōtsuka, of the Imperial Meteorological Observatory.

who knew the district well that although Kobandai looked smaller in bulk than its sister peak, there was no appreciable difference in height, and that snow used to fall on the former earlier. This perhaps might be due to its more northern position. Lieut. Y. Nakashima, of the Surveying Bureau of the Army, who subsequently surveyed Bandai-san, confirmed this view; and after a thorough examination of the topography of the district and the forms of the various peaks, he concluded that Kobandai had been equal to, if not a little higher than, Ōbandai. On the sound judgment of this specialist we can safely place our confidence. We obtained permission to see the map he constructed. It was made with characteristic painstaking care, and every detail was admirably carried out. We are glad to say that our measurements and those of Lieut. Takashima agree well; some difference existed in regard to the heights of crater-walls, but this was more reasonable than otherwise, as they were daily being reduced in altitude by the falling in of the perpendicular edges and steep prominences.

The hight of the crater-bed above the sea level was 1,170* metres or 3,839 ft. The south-western part of Kobandai which was left undestroyed, exposed an almost perpendicular wall of 505 metres or 1,658 ft. overlooking the crater. From these and from the other data already mentioned, it was found that the part of the mountain that broke away had an altitude of 670 metres or 2,198 ft. above the crater, and that 164·6 metres or 540 ft. had been sheared off from its top. On Pl. IX. is given a rough vertical section through the line AB, that is, the section passing through the original summit and the highest fractured edge of Kobandai. The dotted line shows the parts blown off. It will be seen that the vertical line passing through the summit of the mountain was situated about 442 metres or 1,450 ft. N.E. from the fractured edge, its position being indicated on the plan by a cross. The main body of Kobandai and the north-eastern side were completely blown away,

* Also from Messrs. Wada and Ōtsuka's measurements.

leaving a portion of the south western flank. The flank of Kushigamine sloping S.W. met that of Kobandai sloping N.E., practically forming one connected mass, and the consequence was that the latter's destruction was shared by the former in parts where they were so united. Kushigamine now stands overlooking the crater with a bare perpendicular wall 452 metres high.

It is also to be observed that the great fissure-line along which the mountain was rent nearly passed through the summit vertical, or in other words, the fissure-line lay under the summit of Kobandai.

For ease of calculation the shape of the mountain was assumed to be conical, a near enough approximation. Then, subtracting the parts left undestroyed and making other allowances, we found the total volume of the mountain blown away to be 1·213 cubic kilometres or 1,587 million cubic yards. This is equivalent to saying that if the devastated area extending over 70 square kilometres or 27 square miles had been evenly covered with a stratum of earth, rocks, and boulders, this stratum would have had an average thickness of 17·4 metres or 57 ft. The cubic content above given represents the gross total of the volume of the mountain destroyed, including not only the *débris* of earth and rock that descended the mountain-sides, but also the dust, ashes, and boulders which were hurled into the air.

To calculate the weight of the material corresponding to this cubic content, we determined the specific gravity of different kinds of rocks and earth obtained from Bandai-san. The specific gravity of the pyroxene-andesite composing the mass of the mountain differed more or less with the different varieties met with, ranging from 2·58 to 2·71. On the average it may be taken as 2·65. But as the mountain consisted of much looser materials than these rocks such as pumice, scoriæ, &c., the density of the mountain would be much lower than this

value. The mean specific gravity of the earthy materials thrown down by the eruption, as determined by Prof. J. Sakurai, was 2·172.

We may suppose without much error, that the mountain mass of Bandai consisted of rock and earthy materials in the proportion 1 : 2, and then we obtain from the foregoing numbers, as the density of the mountain, 2·33.* From this number and from the already estimated volume, the weight of the mountain destroyed was found to be 2,826,290 million kilogrammes or 2,782 million tons.

Volcanic Products of Bandai-san.

The volcanic rocks that compose the mass of Bandai-san are comparatively of uniform character, and belong to that class of andesite which is of wide occurrence in Japan, viz., the Pyroxene andesite which is now to be briefly described. This rock under its various modifications, may be seen piled up in layers in the side-wall of the newly opened crater, alternating with accumulations of loose products ejected from the volcanic vent in former time, such as pumice, scoriæ, fragments of obsidian, &c. Prof. B. Kotō considers that there are six of these principal layers. The rock-layers which doubtless consolidated from lava-flows, are divisible into two main types; the one being lighter coloured, and the other darker coloured, evidently more basic than the former. The first kind is well observed as a great band on the eastern side-wall down

* Prof. J. Milne in calculating the weight of Japanese volcanoes has assumed the average density to be 2·5. (The Volcanoes of Japan—Trans: Seism. Soc: Japan, Vol. IX. part II, 1886). Prof. T. C. Mendenhall, formerly of the University of Tōkyō, in determining the force of gravity at the summit of Fujiyáma, took the density of that mountain as 2·12, which was the mean of the densities of pulverized and porous rocks. (On pendulum experiments on the summit of Fujiyama for the purpose of ascertaining the force of gravity at that point—Trans: Seism. Soc. Vol. II, 1880). In the authors' Preliminary Report of the Bandai-san Eruption published in the *Official Gazette* of September 27, 1888, the value of the density was taken a little higher, but it was since altered to the present figure.

Kushigamine, more than 10 metres thick, overlaid by reddish coloured loose layers. Lower in position and separated by layers of agglomerate, is found the darker variety. The fragments that compose the agglomerate are also usually of the latter kind. These rocks are, however, essentially of identical mineral composition, and are probably to be considered the different facies of the same magma that supplied the materials for their formation.

The microscopical examination of these rocks shows that the ground-mass is microcrystalline, with a very little of colourless glass basis in the lighter coloured variety between the microlithic plagioclase, while in the darker variety a brown coloured glass is found more abundantly. Numerous magnetite crystals and grains are in both cases always scattered within the general mass, and as enclosures.

The micro-porphyritic mineral components are Plagioclase, and Pyroxenes, which are represented by the monoclinic and the rhombic. The most frequent accessory component is Apatite. Among secondary minerals of less frequent occurrence may be mentioned Tridymite and Iron-pyrites.

The principal characteristics of the porphyritic components are here given :—

PLAGIOCLASE.—The porphyritic crystals are found generally in lathe-shaped outline, having characteristic twin-lamellæ of the albite-type. The extinction-angle of the plagioclase exhibiting these twin-lamellæ varies to a considerable extent; the range being from 20° to 30°. In general character the plagioclase is quite fresh and transparent, often with numerous glass-enclosures, which sometimes fill up the entire space of the crystal and are arranged in distinct zones. In polarized light, the phenomenon of zonal structure is often very typical; the extinction angles differing in the inner and the outer zones, thus showing a difference in the chemical composition of these layers.

The specific gravity of the plagioclase as determined by Thoulet's solution gave as a mean 2.686. These characteristics indicate that the chemical composition should approximate to that of Labradorite.

SANIDINE.—Although this mineral under the microscope is so difficult of detection, we are justified in claiming its existence, since we observed cases in which the basal cleavage face of a glassy felspar devoid of twin-lameliæ, exhibited straight extinction.

The following chemical analysis of the 'feldspathic' components isolated from a rock of Ōbandai, has been made in the laboratory of the Geological Survey Department. Somehow or other, the amount of foreign ingredients is so large that we cannot tell from it the true nature of its composition.

	Per Cent.
$Si\,O_2$	61·26
$Al_2\,O_3$	19·55
$Fe_2\,O_3$	3·36
$Fe\,O$	4·06
$Ca\,O$	3·20
$Mg\,O$	2·54
$Na_2\,O$	3·42
$K_2\,O$	1·22
$H_2\,O$	1·77
	100·38

AUGITE.—This mineral is found in well-defined forms or sometimes in grains. The common type of a twin with the face $\infty P\bar{\infty}$ as a twinning face, is frequently met with. It is usually greenish-yellow in colour, showing a feeble dichroism. It is usually fresh, with glass enclosures, and occasionally small needles of apatite.

HYPERSTHENE.—The occurrence of the rhombic form of Pyroxene has received considerable attention in recent years.

This mineral which has hitherto been regarded as rare, was found to be of wider occurrence than we had expected.*

The rhombic pyroxene generally appears in more slender sections than the augite; breadth to length being as 1 : 3 to 1 : 5. Under polarized light the interference-colour is weak, and always shows a straight extinction. The pleochroism is very marked; $\parallel \gamma =$ light green, $\perp \gamma =$ greenish brown.

On examining the macropinacoidal section, under a convergent polarized ray, we can often very distinctly observe a biaxial interference-figure, which, however, on account of the thinness of the section appears elliptical. The dark cross which traverses the middle of the figure under crossed nicols, passes into an hyperbola as we rotate the section.

The rhombic pyroxene is often found in a cross shaped twin, the vertical axes of the two individuals making an angle of 60° with each other. This twin is therefore that which has often been met with in other localities, the twinning plane being $P\bar{\infty}$. Parallel-intergrowth of the rhombic phyroxene with angite is also found. This has been dwelt on at length in the description of the Bonin specimens†. Though in specimens from Bandai this is not so clearly defined, yet we have found some cases in which this phenomenon was very characteristically developed, the crystal of the rhombic pyroxene being surrounded on both sides, or flanked on one side, by an augite band.

The rhombic pyroxene isolated from the rock by means of Thoulet's solution and then lightly washed with hydrofluoric acid, was analyzed by Mr. T. Shimizu. It was impossible to separate the rhombic pyroxene from the augite. The following analysis is therefore that of a mixture :—

* An interesting Japanese occurrence of this mineral is in the Bonin Islands. See St. Jour. Sc. Coll. Vol. III., Part I.

† 1. c. p. 78.

	Per Cent.
$Si\ O_2$	51·80
$Al_2\ O_3$	trace
$Fe_2\ O_3$	1·80
$Fe\ O$	18·86
$Mn_3\ O_4$	1·03
$Ca\ O$	7·96
$Mg\ O$	18·84
	100·38

This leads to the composition nearly equivalent to $2\ Fe\ Si\ O_3 + 3\ Mg\ Si\ O_3 + Ca\ Si\ O_3$.

MAGNETITE.—It is very abundant in grains, and as enclosures, especially in the pyroxenes.

APATITE.—The crystals of this mineral sometimes occurs in a very characteristic form. It is dichroic; $\parallel \dot{c}$ = brownish, and $\dot{c} \perp$ = yellowish. The crystals usually with fine longitudinal striæ, and with transversal cleavage-fissures. This kind of apatite is very abundant in the lighter coloured rock which was found in the bottom of the conical hole at Mine-yama.

TRIDYMITE.—This mineral is seldom found in the fissures in microscopic form. In the rock imbedded within the hole at Mine-yama just referred to, it was found in well-defined crystals visible to the naked eye, nearly ·5—1 mm. in size, lining the cavity of the rock in the manner of a druse. Some of them were found characteristic twins. When taken out of the cavity and examined closely the crystals were found in hexagonal plates, in combination with the faces (when referred to the *hexagonal* axes) oP, ∞P, P, ∞P_2, flattened along the base. Under crossed nicols, however, the plate was seen to consist of innumerable patches crossing at an angle of nearly 120°, and showing oblique directions of extinction. The specific gravity of the mineral determined by swimming it in the Thoulet's solution was 2·272.

For the chemical analysis, given below, of the Bandai rocks and ashes we are indebted to the Professor T. Wada, the Director of the Geological Survey. They are the result of a very careful analysis by Mr. T. Shimizu :—

	I.	II.	III.
$Si\,O_2$	59·66 %	59·56 %	59·47 %
$Ai_2\,O_3$	15·51	16·10	17·12
$Fe_2\,O_3$	3·76	6·28	2·33
$Fe\,O$	5·40	3.02	5·69
$Mn_3\,O_4$	1·40	1·80	——
$Ca\,O$	6·56	6·32	7·24
$Mg\,O$	3·67	3·08	4·04
$Na_2\,O$	2·50	3·09	2·23
$K_2\,O$	1·08	·80	·30
S	·59	——	——
$P_2\,O_5$	·18	·18	——
Loss by ignition—		·44	1·55
	100.31	100·97	99·77

Insoluble portion in HCl. Insoluble portion in HCl.
= 75·34 % = 85·34 %

I. is a greenish-black rock taken from the rugged cliff of the partially destroyed wall of Yugeta-yama, containing a small quantity of iron-pyrites.

II. is a reddish coloured rock, very frequently met with within the *débris*, especially in the conical mounds, somewhat powdery at the surface, due to the fumarolic action to which it was subjected within the volcano. There is more sesquioxide of iron in this rock than in the others. The sample for the analysis was obtained from the ejected masses near Tokoro-sawa, a ravine on the eastern side of Bandai.

III. is the analysis of a rock from Bandai given by S. Nishiyama in his report to the Geological Survey, in 1887. The exact locality of this rock is not mentioned.

From these results it will be seen that the rocks of Bandai are nearly identical in their composition. We may, nevertheless, distinguish two types as we have already stated. One is a coloured rock, the structure being usually porphyritic; the porphyritic components being proxenes and microtine plagioclase within a greyish coloured ground-mass. A typical example of the first type may be seen exposed on the side-wall of the new crater, as an extensive sheet in the great cliff forming now the western side of Kushigamine. A similar kind of rock was also found near the summit of Ōbandai. Microscopically examined the greyish white ground-mass is microfelspathic in character, with a small amount of colourless glass basis. All the mineral components are quite fresh. The plagioclase of this rock was found to have a specific gravity of 2·682.

The other type of the pyroxene-andesite is a darker coloured rock evidently more basic than the first and resembling Basalt in the outer appearance; the glassy plagioclase being interspersed within the dark, often compact, and resinous ground-mass, thus presenting a marked porphyritic structure.

Besides occurring in the form of a sheet of solid rock, it is also abundant among the fragments which compose the agglomerate, being, in this case, often scoriaceous in appearance. Under the microscope, the ground-mass is micro-crystalline, with a more or less brownish coloured glass basis. In the scoriaceous rock just referred to, the hypersthene crystal is often highly pleochroic. The specific gravity of the plagioclase determined with Thoulet's solution is found to be little higher than that contained in the first type, being on an average 2.691.

To this type also belongs the rock which is exposed in a rugged cliff of the half destroyed Yugeta-yama, on the western edge of the new crater, and the analysis of which is given above (I.). In this rock there is a very light brownish coloured

The general description of the volcanic ash or dust that fell during the eruption has already been given (p. 158). It has a bluish-grey colour, is usually very fine grained, but sometimes mixed with coarser rock-fragments. The microscopic examination of the dust shows that it is essentially made up of the same components as the pyroxene-andesite described, proving that it was derived by the mechanical trituration of this rock. It consists of minute particles of the microfelsitic ground-mass, mixed with crystal-fragments of Plagioclase, Sanidine, Augite, Hypersthene, Magnetite, and Apatite needles with a very small amount of glass.

A specimen of the dust was brought from the town of Miharu, 38 kilometres to the east of Bandai-san. It is essentially the same as that which fell in the immediate neighbourhood of the volcano, only that it is somewhat finer grained. In mineralogical composition also, it is almost exactly similar, being chiefly made up of the finer particles af the rock, the crystal-fragments of plagioclase, the pyroxenes, and magnetite. These ashes, being comparatively heavy, do not seem to have fallen to any very great distance, thus differing from the fleecy pumiceous materials produced from molten lava at the time of other volcanic eruptions.

The following chemical analysis (I.) of the ash obtained by Mr. S. Ōtsuka of the Geological Survey, from Hikage in Biwasawa, when compared with those of the andesite rocks already given, will show how close is the agreement.

This ash, when treated with a mixture of hydrochloric acid, mixed with nitric acid in order to dissolve out the sulphur, gave a residue amounting to 32·92 per cent. This, when analyzed, gave the result as in column II.

	I.	II. Insoluble portion.	III. Soluble portion (by difference.)
SiO_2	59·70 %	40·11	19·59
Ai_2O_3	16·68	6·75	9·93
Fe_2O_3	5·43	1·44	3·99
FeO	2·05	—	2·05
Mn_3O_4	·98	trace	·98
CaO	5·20	1·75	3·45
MgO	2·35	1·08	1·27
Na_2O	2·67	1·25	1·42
K_2O	·99	·71	·28
S	2·25	—	2·25
SO_3	·95	—	·95
P_2O_5	·15	—	·15
Loss by ignition	·90	—	.90
	100.30	53.09	

The ash contained some soluble matters which on being extracted with cold water gave traces of lime, chloride, and sulphate.

The analysis of another, and a somewhat more stony sample of the ash was made by Mr. H. Yoshida, of the Imperial University, with the following result:—

SiO_2	61·82 %
$Fe_2O_3 + Al_2O_3$	28·10
CaO	5·73
MgO	·79
K_2O	1·10
Na_2O	2·42
	99·96

Reports.

Under this heading, we arrange in tabular form the answers to inquiries made to schoolmasters and others living in the provinces near Bandai-san. We have already referred to the

particulars obtained in this way, and the great help we derived in the preparation of our paper from the answers so received.

In the Table when the phenomena under consideration were reported not to have been observed, the space is marked with a dash; when it was not known whether certain phenomena occurred or not the corresponding space is left blank.

Unless otherwise stated, the date refers to the 15th of Jury, 1888—the day of eruption.

1 *Shaku* is nearly equivalent to 0·303 metres, or one foot.
1 *Sun* $= \frac{1}{10}$ of 1 *Shaku*.
1 *Bu* $= \frac{1}{100}$ of 1 *Shaku*.
1 *Ri* = 3·93 kilometres, or 2·44 miles.

REPORTS.

Name and Address of Observers.	Direction and Distance from Bandai-san.	Sound.	Ashes.
No. 1. T. Uda, Kokai village, Yama-kōri, Province Iwashiro.	E.S.E. 5 kilometres. 3.2 miles.	A black column of smoke ascended high into the air; the sound of the explosion was something terrific, lasting for about 30 minutes.	Ashes fell in abundance in the neighbourhood of the mountain for about an hour and it was not until about 4 o'clock p.m. that it entirely ceased. I was bathed by ashes. The thickness was 1 *shaku* near Shirakijō, and 6 *sun* near Hinokuchi. The ashes were powdery, but occasionally mixed with rocky fragments which struck upon our bodies.
No. 2. U. Hayakawa, Sasakawa village, Yama-kōri, Province Iwashiro.	W. 30 kilometres 18 miles.	A rumbling sound was head by some.	—

Earthquakes.	Meteorological Condition.	Miscellaneous Notes.
No earthquakes on previous days. A few minutes before the eruption curious rumblings were heard, and while we were wondering what was the matter, a violent shaking of the earth occurred about 3 times. At the end of the 3rd shock, a black column of smoke ascended from Bandai-san. The character of this earthquake was different from that usually experienced, heavy up and down movements predominating.	Very fine. No cloud streaked the heaven. It was however somewhat hotter than usual. No wind before the eruption. Soon after the eruption, a great whirling wind suddenly swept over the eastern part of the mountain with great violence, destroying Shibutani, Shirokijō, Ojigakura, etc.	Some people say that they have seen fire on the mountain; I saw two flashes of lightning from the rising steam. At Oda village more than 2 *ri* away on the eastern side of the mountain, a spring became as warm as hot bathing water while the ashes were still falling; but at about 4 o'clock p.m. it became cold again. This is evidently due to the effect of heat imparted by falling ashes, which often scalded the naked parts of the body. The ashes also had the smell of sulphurous acid. Thunder claps were heard, followed by heavy rain continuing 3 or 4 minutes, which was also warm having the temperature of at least 70-80° Fah.
No earthquake on previous days. On the 15th a slight shock of very short duration was felt. It passed unheeded by most people.	Very fine. Thermometer 88° F.; atmosphere calm. At the time of the eruption a gentle breeze blew from the west.	Two travellers who were at the time of the outburst, resting at the pass of a neighbouring ridge, observed black clouds rising from behind Bandai, among which were occasionally seen reddish coloured objects. The phenomena lasted for a few minutes; after this a white column of steam was seen ascending from these places; at the same time Kobandai entirely vanished from view.

Name and Address of Observers.	Direction and Distance from Bandai-san.	Sound.	Ashes.
No. 3. S. Yamamoto, Kitagata, Yama-kōri, Province Iwashiro.	W.N.W. 15.7 kilometres. 9.8 miles.	Sound like distant thunder.	No ashes fell.
No. 4. T. Kamizuma, Tajima, Aizu-kōri, Province Iwashiro.	S.S.W. 4.73 kilometres. 29.3 miles.	Rumbling sound heard twice. It was, however, so slight that it was unnoticed by many.	—
No. 5. H. Katō, Kawaguchi, Ōnuma-kōri, Province Iwashiro.	W.S.W. 47.1 kilometres. 29.3 miles.	At 8h. 40min. and 9h. 15min. a.m., sound was heard.	No ashes.
No. 6. N. Yamasaki, and T. Mafune, Fukuyoshi, Asaka-kōri, Province Iwashiro.	S. 21.6 kilometres. 13.4 miles.	The detonation of the explosion was very intense, continuing for nearly 5 minutes. It was also heard for several hours afterwards. People regarded the rumbling as a premonitory sign of the earthquake.	No ashes.

Earthquakes.	Meteorological Condition.	Miscellaneous Notes.
A slight shock at 4 p.m. on the 12th.	Very fine; calm in the morning; it was little hotter in the afternoon, when the thermometer stood at 88° F., and the northern wind began to blow.	Black columns of smoke were seen rising to a great height; neither lightning nor fire were seen. There was observed also a light reddish coloured cloud spreading at right angles to the columns of the smoke.
About 5 days before the eruption somewhat strong earthquakes occurred twice. A slight shock at about 7 a.m. on the day of the explosion.	Very fine; some patches of cloud seen in the eastern sky. Western breeze at the time of the eruption.	No lightning or smoke seen; no change in rivers, springs, wells, etc.
At about 0h. 30m. a.m. on the 11th of this month, an earthquake was felt.	—	—
No earthquake on previous days. At about 8 a.m. a very severe shaking experienced, continuing for 5 minutes. It was very violent and the people felt as if the ground was suddenly upheaved.	Very fine before the eruption; the wind was northerly; after the eruption it appeared as if it had changed to N.W.	From the ascending columns lightning was emitted. The smoke soon covered the top of Bandai. N.W. wind blowing at the time; ashes fell at the village of Yokohama, nearly 2 *ri* N.E. from this place, coating the vegetation with greyish powder.

Name and Address of Observers.	Direction and Distance from Bandai-san.	Sound.	Ashes.
No. 7. S. Sugeno, Harimichi, Adachi-kori, Province Iwashiro.	E. 45.2 kilometres. 28 miles.	People inside the houses did not notice the sound. Peasants who were working in the fields heard it. It continued for nearly 5 minutes. The screech of the pheasant which is generally heard during an earthquake, was also noticed.	No ashes.
No. 8. T. Katō, Naganuma, Iwase-kori, Province Iwashiro.	S.S.E. 35.3 kilometres. 22 miles.	Low rumblings noticed.	—
No. 9. — Motomiya, Adachi-kōri, Province Iwashiro.	E.S.E. 29.5 kilometres. 18.3 miles.	At about 7h. 30 minutes a.m. a roaring sound.	On the north-western mountains, a peculiar cloud of sharply defined form appeared, which gradually spread out in a circular form, like an umbrella, at the same time becoming lighter in colour. As the cloud spread wider, gray coloured ashes of the size of millet grains began to fall at about 8 a.m. This was followed by the fall of powdery ashes ; all the vegetation wore a grey colour.

Earthquakes.	Meteorological Conditions.	Miscellaneous Notes.
Nobody felt any shock.	Very fine, and no cloud, calm, temperature reaching to 90° F. in sunshine. N.W. wind at the time of the outburst.	While the heaven was clear, a very peculiar cloud (which I afterwards learned to have been steam) appeared near Adatara - san. There was neither lightning nor fire.
At 7 a.m. a slight shock, before we heard the rumbling noises.	Very fine; calm. Weather somewhat changed in the afternoon.	A black streak of cloud appeared, with beautiful stripes of purple, red, yellow, and green, probably caused by the reflection and refraction of sunlight falling upon steam.
Strong shock was felt.	—	Ascent of smoke observed. The umbrella-shaped cloud disappeared at about 10 a.m.

Name and Address of Observers.	Diraction and Distance from Bandai-san.	Sound.	Ashes.
No. 10. Wakamatsu, Aizu-kōri, Province Iwashiro.	S.W. 15.7 kilometres. 9.8 miles.	Thundering noises were heard accompanied by the ascent of black smoke.	No ashes.
— No. 11. Fukushima, Shinobu-kōri, Province Iwashiro.	E.N.E. 37.3 kilometres. 23.2 miles.	Distant sound was heard.	—
No. 12. K. Mita, Onoshin-machi, Tamura-hori, Province Iwashiro.	E.S.E. 74.8 kilometres. 40.2 miles.	At about 8 a.m., the sound was heard thrice at short intervals by those who were outside of houses.	The fall of ashes began at about 9 a.m. and continued till about 12.
No. 13. M. Murata, Miharu, Tamurakōri, Province Iwaki.	E.S.E. 38 kilometres. 24 miles.	Tolerably loud was heard.	Ashes began to fall from about 9 h. 30 min. a.m., and continued until 2 h. 30 min. p.m. During this interval the atmosphere had a misty appearance; the film of the ashes turned vegetable and other objects into greyish hue. Ashes fell at one time so thickly as to fill the eyes and nostrils of the passers-by. The street was almost impassable. [A sample of the ash was sent.]

Earthquakes.	Meteorological Condition.	Miscellaneous Notes.
There was a smart shock shortly before the eruption, then it was followed by violent heavings of the ground. The houses were observed to sway.	Fine weather, very gentle breeze.	Smoke ascended very high.
A moderate earthquake.	—	—
A shock of short duration on the day before the eruption.	Very fine; 82° F. at noon; somewhat cool at 7·8 a.m.	On account of ashes, the atmosphere became very dim and heavy; in the direction of Bandai a thick cloud appeared.
Earthquake occurred before the eruption, continuing for about 20 seconds. It felt as if something had fallen in the next room. In general character it differed from the shocks usually felt.	Very fine; gentle N.W. breeze, 85° F.; it was a little stronger after the eruption.	A dark coloured cloud seen in the N.W., gradually spreading as it ascended. At about 10 h. 10 min. a.m. that part of the heavens became so thickly covered with misty cloud that we could not see the mountain for 20 minutes.

Name and Address of Observers.	Direction and Distance from Bandai-san.	Sound.	Ashes.
No. 14. Taira, Iwamaikōri, Province Iwaki.	S.E. 86.4 kilometres. 53·7 miles.	Peculiar sounds were heard by some continuing for about 2 minutes.	At about 10 a.m. finely powdered ashes fell, coating the vegetation and roofs.
No. 15. N. Oishi, Kohama village, Narahakōri, Province Iwaki.	E.S.E. 86.4 kilometres. 53·7 miles.	Noises heard for about 3 minutes.	A greenish white coloured powder or ash fell forming a thin coating over mulberry leaves, &c. In the village of Kawauchi, 5 *ri* west of this place, the ashes fell in the form of lumps about the size of a pea.
No. 16. F. Kurosawa, Shimo-Ishii villages, Shirakawa-kōri, Province Iwaki.	S.S.E. 78.5 kilometres. 48.8 miles.	—	—
No. 17. Watrai, Watari-kōri, Province Iwaki.	N.E. 80.5 kilometres. 50 miles.	—	—
No. 18. S. Chika and R. Ashikawa, Yonesawa, Okitama-kōri, Province Uzen.	N. 33.4 kilometres. 20.7 miles.	At about 8 a.m. thundering noises were heard in the southern mountains.	No ashes.

Earthquakes.	Meteorological Conditions.	Miscellaneous Notes.
Feeble shocks at about 8 a.m. on the 14th, and at about 4 p.m. on the 15th.	Very thick mist in the morning, but gradually began to clear away from about 8 a.m. It was quite fine at noon. Thermometer 75° F., at 6 a.m., 90° F. at 12 a.m. About 8 a.m. W. wind prevailed but afterwards turned to S. At 11 a.m. it became S.E.	The thick smoke rising from Bandaisan, which was generally regarded as cloud, looked black and somewhat reddish. During sun-set sparkling rays of red light were emitted from the cloud.
—	Very fine and calm early in the morning. At about 9 a.m. a black cloud appeared on the west, and became dark, but it cleared again in the evening. Thermometer 85° F.	In the direction of Bandai, a cloud of an elliptical form was seen.
—	Very fine; temp. 95° F. at noon; a gentle north wind.	—
At 11 h. 50 min. a.m. a slight earthquake lasting for only about 10 seconds was felt; motion horizontal.	Cloudy, a warm wind, 78° F. at noon.	—
A feeble shock at 3 p.m. on the 14th; at 7 h. 30 min. a.m. and at 8 h. 20 min. a.m., on the 15 feeble earthquakes; the former was a little stronger than the latter.	Extremely fine. 90° F. at noon. W. wind.	While the weather was extremely fine, we observed the rise of a peculiarly grey coloured cloud-like smoke in the southern sky over Azuma-san.

Name and Address of Observers.	Direction and Distance from Bandai-san.	Sound.	Article.
No. 19. T. Kusaka, Shikase village Higashi-Kanbara-kori, Province Echigo.	W. 53 kilometres. 33.2 miles.	—	—
No. 20. Takai-kōri, Province Shinano.	W.S.W. 164 kilometres. 102 miles.	It was reported that a peculiar detonating sound was heard on the morning of July 15th; it was attributed to the roaring sound sometimes audible from Asama-yama.	—
No. 21. K. Nakashima, Kinboku-san, Island Sado.	W.N.W. 161 kilometres. 100 miles.	While I, in company with others, was ascending Kinboku-san in the island of Sado on the morning of July 15th, we heard curious dull rumblings which we thought to be the firing of heavy guns in the neighbouring harbour.	—

Earthquakes.	Meteorological Conditions.	Miscellaneous Notes.
At about 4 p.m. on the 14th a smart shock was felt and was soon followed by strong shakings of the ground which lasted less than 3 min.	Very fine; 85° F. at noon; gentle E. breeze.	After the eruption, the water of Akagawa diminished and became turbid.
—	—	—
—	—	—

Letters of inquiry were sent to the following places, but we received answers to the effect that nothing which could certainly be referred to the influence of the volcanic eruption was noticed in these districts:—

Localities.	Direction from Bandai-san.	Distance from Bandai-san.
Sanjō, Province Echigo............	W.	96.2 kilm. 59.8 miles.
Mizuhara, Province Echigo	W.N.W.	76.6 kilm. 47.6 miles.
Muramatsu, Province Echigo ...	W.	76.6 kilm. 47.6 miles,
Nagaoka, Province Echigo	W.	106.0 kilm. 65.9 miles.
Mito, Province Hitachi	S.S.E.	135.5 kilm. 84.2 miles.
Takahagi, Province Hitachi	S.S.E.	106.0 kilm. 65.9 miles.
Noki, Province Shimotsuke	S.	153.2 kilm. 95.2 miles.
Nikkō, Province Shimotsuke ...	S.S.W.	106.0 kilm. 65.9 miles.
Karasuyama, Prov. Shimotsuke...	S.	104.1 kilm. 64.7 miles.
Tochigi, Province Shimotsuke ...	S.S.W.	133.5 kilm. 83.0 miles.
Shiobara, Province Shimotsuke...	S.	70.7 kilm. 43.9 miles.
Namiye, Province Iwaki	E.	82.5 kilm. 51.2 miles.
Haranomachi, Province Iwaki ...	E.	78.5 kilm. 48.8 miles.
Ishikawa, Province Iwaki	S.E.	62.8 kilm. 39.0 miles.
Yamagata, Province Uzen.........	E.N.E.	79 kilm. 49 miles.
Iwahashi, Province Uzen	N.W.	86.4 kilm. 53.6 miles.
Sendai, Province Rikuzen.........	N.E.	103 kilm. 63.4 miles.

DESCRIPTION OF THE PLATES.

PLATE I.

Map of Bandai-san district. The area devastated by the *débris* of rock and earth caused by the destruction of Kobandai is distinguished by the grey colour. The position and form of the crater are indicated.

Large and small conical mounds standing out from the surface of *débris* in immense numbers.

Principal steam-fissures in the crater.

Hot springs.

Marks the direction of the hurricane-blast and the area swept by it.

Heights are given in metres.

PLATE II.

Fig. 1.—Distant view of Bandai-san from N.W. side, as seen from the hill ridge of Nagamine.

a. Ōbandai.

b. The rugged and the highest part of the crater-wall.

c. Kushigamine.

d. Marumori-yama.

e. Kaminoyu.

f. Shimonoyu.

g. Kawageto-yama.

h. Mud-field.

The forest in the foreground being situated on a ridge, escaped destruction by the *débris*.

Fig. 2.—View of Numano-taira near the edge of the new crater; the perpendicular cliff of Ōbandai facing this spot. Large hollow depressions (*k*) are found partly filled with water (p. 170). The ground is covered with grey coloured ashes and smaller rock fragments. For other letters refer to Fig. 1.

(From sketches by Y. Kikuchi.)

PLATE III.

Fig. 1.—Distant view of Bandai-san as seen from the outskirt of Inawashiro, with the village of Miné in front.

a. Ōbandai.

b. Kushigamine.

c. Akahani-yama.

d. The smaller mud-stream, which ran down through the Biwa-sawa (the ravine between *b* and *c*), descending upon, and burying a part of the village of Miné (p. 155).

e. Village of Miné.

(From Photograph.)

Fig. 2.—Sketch taken from Biwa-sawa.

a. Ōbandai with rugged and precipitous wall on the northern side.

b. Kushigamine.

c. Akahani-yama.

d. Upper course of the mud-stream toward Miné.

f. Futatsu-iwa (p. 146).

(From sketch by Mr. H. Hirauchi.)

PLATE IV.

Fig. 1.—Extensive and nearer view of mud-field of Miné.

Fig. 2.—Example of large boulders carried down along with the mud-current and forming conical mound near Kawakami. Mounds of this kind were formed on the *débris* in great numbers (p. 157).

(From Photographs.)

PLATE V.

A rock mound prominently standing out in the inside of the crater, that formed one of the stations of the survey.

Encircling crater wall on the background; Kushigamine on the left with its fractured side exposing volcanic strata; on the right a part of the rugged cliff seen through the stream.

The gigantic block on the right foreground is one of the many boulders scattered about in the crater.

PLATE VI.

Mud-stream in Nagase Valley below Kawakami facing S.E. *Débris* of rock and earth descending in a swift torrent left wavelike traces on the side of the hill (p. 155), and filled up the valley perhaps not less than 40 metres deep.

PLATE VII.

Fig. 1.—Crater as seen from the north near the village of Hibara, three weeks after the eruption, and at a distance of 9 kilometres—the position from which the grand view of the devastation could be seen with full effect. Among the *débris* from the crater downward, may be seen innumerable numbers of conical mounds. On the right hand are seen the hillsides bared by the torrent of mud. The main feature of this figure is analogous to Fig. 1., Pl. II. For the names of the principal peaks refer to that plate.

Fig. 2.—View of the crater twenty days after the eruption, from its edge just over the solfatara of Kaminoyu, looking down the crater, at the bottom of which a small lake or pond may be seen. On the right hand side is the characteristically rugged cliff of Yugeta-yama, on the proximity of which are numerous withered trees stripped of leaves. In the middle of the figure are numerous fissures puffing off steam, and behind stands Kushigamine. The distant mountain in the background is the old volcano of Dake-yama.

Fig. 3.—Distant view of Bandai-san from its south side as seen from the town of Wakamatsu, four weeks after the eruption. The most prominent point peak is Ōbandai, exposing on its flank a bare valley called Kara-sawa. The dotted line on the left shows the original form of Kobandai previous to the eruption. The prominence immediately below is the remains

of Yugeta-yama. Down below is seen Marumori-yama as a small protuberance. The peak to the right is Kushigamine. The hill ridges in the foreground are part of the Aizu-plateau.

(From sketches by Y. Kikuchi.)

PLATE VIII.

View of Bandai-san from its north-eastern side at distance of about six kilometres, from the former site of the hamlet of Akimoto. The linear arrangement of steam-fissures is at once apparent to the eye. The level tract in the foreground shows the levelling effect by the mud-stream, in which may be seen accumulations of water. A little farther away we find innumerable conical mounds. Just above the masses of these mounds on the left hand side, is seen the rocky exposure of a ridge which has had its loamy crust completely scraped off. Between this ridge and the prominent tree-covered peak of Kushigamine just behind, stretches the valley of the Nagase-gawa.

On the right hand side behind the group of conical mounds is seen the extensive slope, formerly known as Ōbudaira, converted into waste desert. The prominence at the termination of the steam column is Marumori-yama.

(From photograph taken by Prof. W. K. Burton one week after the eruption.)

PLATE IX.

Plan.—Form of the crater as deduced from the triangulation survey. The contour lines in the crater indicate roughly the principal elevations and depressions.

× The original top of Kobandai which is in the line of the steam fissure.

* Principal steam fissures.

Section.—The profile of the crater through the line *A B*, or the line passing through the original top of Kobandai and the highest part of the crater-wall. The dotted line shows the part that was blown away.

The heights are given in metres.

NOTES ON BANDAI-SAN.

By Professors Cargill G. Knott, D.Sc., F.R.S.E.,
and C. Michie Smith, B.Sc., F.R.S.E.

[Read May 31st, 1889.]

On the 23rd and 24th of May 1889, we paid a visit to Bandai-san with the intention simply of viewing the scene of the great eruption of last year. We had the privilege before starting of reading some of the early proof-sheets of Professors Sekiya and Kikuchi's memoir on the eruption; * and were to a certain extent prepared for what we were to witness. On comparing our experiences with the records of the earlier observers, we found much of particular interest to the geologist, and were also enabled to arrive at certain definite conclusions which seem to have escaped the notice of our predecessors in the field.

Our notes are conveniently grouped under three headings, as follow:—

I.—The effects of erosion.

II.—The character of the outburst that produced the so-called Miné stream.

III.—The much disputed question of the origin of the holes in the vicinity of the mountain.

These we shall take up in order.

I.—The Effects of Erosion.

One of the chief features of interest to a visitor to Bandai-san

* Journal of the College of Science, Imperial University, Vol. III; also published in the present volume of the Transactions of the Seismological Society of Japan (see preceding paper).

at present is the wonderful way in which the action of flowing water in hill sculpture is illustrated. The whole area of the recent deposits has been cut and carved till it shows on a fairly large scale the way in which hills may be moulded into the most fantastic shapes by the continued action by even very small streams. Without a carefully contoured map of the parts covered by the deposits it is impossible in many cases to determine with accuracy the amount of erosion. In others, however, where the streams have cut out narrow gorges and left the banks at each side of nearly the original height, it is easy to get an approximate measurement.

The part which we chiefly studied was the mud-field above Miné. As shown in some of the photographs taken very soon after the eruption the surface of this field was fairly uniform; at least there were no marked channels in it. Now, on the other hand, it is cut up by three deep channels and a number of smaller ones, down which streams of water are flowing. Plate I, enlarged from a photograph, shows some of the chief features of this erosion. The stream, which is only a small one, is flowing in a deep cutting with the sides sloping almost at the angle of repose of the material. Just below the part shown the stream turns through nearly a right angle, while at the upper part is a large block of stone under which the water has cut a tunnel. A little above this there is a very fine cutting which we measured. Its depth was found to be 80 feet and the width at the top almost the same, so that the sides are sloping at an angle of above 63°. Higher up the cuttings were even deeper, and we estimated some of them at from 120 ft. to 130 ft; one may have been as much as 150 ft. Plate II., also enlarged from a photograph, shows one of the best sections, taken a little higher up the stream. It should be mentioned that these photographs were taken on a very misty day, so that the definition is not so clear as might be desired.

At first sight it seemed very difficult to believe that such deep cuttings could have been excavated by comparatively small streams, in so short a time, especially since we found that

the water in the lower part of the stream was beautifully clear and apparently almost free from suspended matter. Higher up, however, the water was muddy, and an examination of the ground showed that several causes had been at work to hasten the erosion. The most important of these was probably the damming up of the water of the streams by the falling earth, and the consequent accumulation of water behind the barriers. It is evident that there have been several such accumulations of water, and that in some cases the escape first began by channels other than those through which the final rush came. That such a rush of water as must have resulted from the opening of one of these dams would cause very rapid erosion is well recognized. It is very likely, from the nature of the soil, that the escape would not have been so rapid as to cause the water to spread over a wide area, but rather that as the channel through the barrier became deeper and deeper the volume of water would be kept at flood level for a considerable length of time. Another cause of the rapidity of the erosion is to be found in the way in which many parts of the deposit are saturated with water from springs or from small streams on the hill sides. In many places the ground is so soft that one has to pick his foot-steps with great care in crossing it. The large amount of snow which was still to be found on the mountain when we visited it probably indicates that the snowfall last winter was very heavy. Though the covering of snow no doubt helped to protect a large part of the ground from erosion the flood caused by the melting of the snow would be effective agents in deepening the water channels. It was evident that the steepness of the slope of the banks of the stream was so great that in some cases the snow had slid down from them as from the roof of house. This had, doubtless, caused considerable damming up at times, for even now in more than one case the water escapes by a tunnel cut under a mass of snow. The upper surface of the snow is in many cases so thickly coated with fallen earth that one would never suspect that it was snow if it were not for the whiteness of the lower ends where pieces

have been broken off. While the erosion is now taking place mainly along certain definite lines which apparently coincide approximately with the former water courses, this has not by any means been always the case, and the result is that in some places very narrow ridges of earth have been left separating a now dry channel from the present bed of the stream, both slopes being at almost the angle of repose. Wind and rain will soon wear down these ridges, and before long the general appearance will be greatly changed. An interesting feature which illustrates very prettily the formation of waterfalls on rivers, is the effect of boulders in stopping the erosion above while the action still goes on below. Thus a small waterfall is formed. If the boulder is a large one so that it reaches to some distance beyond the channel on each side the fall may become a pretty high one: but if it be a small boulder it soon gets undermined and falls down leaving the upper part unprotected. High up the valley the slopes are at a very steep angle (as much as 35° in some cases), but the covering of earth is not very thick, and what there is, is protected to a certain extent by roots, stumps, and branches of fallen trees, so that there is much less marked erosion. It is worth noting that even in the deepest cuttings the old river bed has not yet been reached. In the crater itself there are some admirable examples of weathering of another kind. The photographs taken immediately after the explosion show some very fine tors and piles of rocks and *débris*. These are now very much reduced and smoothed by weathering, and are evidently rapidly falling (compare Plate III. with Sekiya and Kikuchi's Plate V.). The weathering of some of the rock masses is very interesting. In particular there is a kind of stone, probably basaltic, which has been apparently ejected from the interior of the mountain. This rock becomes perfectly white by exposure to the air, and scales off in layers more or less spheroidal. These layers are almost pure silica, and are very friable and soon crumble down into dust.

In the contoured map of the crater shown by Sekiya and

Kikuchi (see Plate IX. of their paper), two fairly large ponds are shown, the one towards the south side and the other a little further to the north-west. The latter has now distinctly diminished in size; and the former has quite disappeared, its site being taken by a large sandy flat, large enough to serve as a good cricket pitch. Immediately to the south of it the lower slopes of the crater wall begin to rise, while to the north is a series of rugged stony knolls, confusedly arranged, and in many cases covered with a thick layer of papillæ. Another smaller sandy flat lies close to the north-west of the "cricket pitch," and it also marks the site of a former pool of water.

The view to the north of the crater was bleak and bare in the extreme. Instead of several good sized lakes as in the days immediately succeeding the eruption, there was one very large expanse of water and a few smaller patches. This large lake reached as far as Hibara, and was some 5 or 6 miles long and fully a mile broad at the broadest part.

Generally speaking, the appearances in the crater had during the ten months since the eruption altered chiefly in three particulars. There was the direct action of erosion in smoothing down the rugged and fantastic piles and tors that were at first so characteristic a feature. There was the secondary effects of a rapid erosion in the silting up of ponds and their conversion into level sandy stretches. And finally there was the marked diminution in the intensity of the fumaroles, which existed in all states, from energetic bubbling and snorting to a gentle intermittent hissing at the bottom of a conical cavity; and so by a gradual transition to an extinct condition, in which perhaps the bottom of the cavity was still warm to the touch.

What seems specially worthy of note is the amazing rapidity of the erosion everywhere displayed, a result of the loosely compacted nature of the new surface soil. Even with this consideration present to the mind, it is difficult to credit running water with such rapidly erosive powers. There seems little doubt that in the Bandai-san catastrophe and the subsequent

action of ordinary geological agents we have an example of what has been in Japan a frequent mode in which the surface configuration has been effected.

II.—The Character of the Outburst towards the South-East.

The small plateau of Numanotaira lies now between three conspicuous peaks, namely Ōbandai, Akahani-yama, and Kushigamine. The eastern crags of Ōbandai look due east across Numanotaira out between Kushigamine on the north and Akahani on the south. Akahani extends a broad shoulder northwards towards the southern aspect of Kushigamine. In a gorge between them the main stream of the Biwasawa has its source. The broad ridge connecting Kushigamine and Akahani may be regarded as the eastern limit of Numanotaira. A deep hollow with a marshy pool at the bottom lies just in the centre of this ridge. All over this region a thick forest originally spread, extending itself right and left over the slopes of Akahani and Kushigamine. The damage done to this forest varies greatly according to place. In some places the devastation is complete—ghostly trunks stand shorn of leaves, branches, and bark—while in others the bared branches still remain with some show of vitality.

Generally speaking, the damage done to the trees on the lower slopes where none of the mud stream has accumulated is distinctly less than that done over the higher slopes of Akahani and Kushigamine and over the broad ridge that connects them. We are unable to determine the exact character of the damage done to the trees which originally occupied tracts now covered with the mud stream. Probably, however, these trees were overwhelmed and prostrated before the earth torrent, except perhaps in its lower reaches. As we passed up the hill on the right bank of the Biwa, we found ourselves on a steep spur whose surface was covered with the material that had been shot from Kobandai. To what depth this covering lies it was impossible to judge; but there was abundant evidence

that, as we ascended, the depth of the deposit thinned off. We were at this time far above the bed of the Biwa, where probably the mud-stream originally lay thickest.

The first sign of the deposit thinning off was the appearance of trees and shrubs tremendously shattered but still left rooted *in situ*. Shortly after these remnants of a wrecked forest were first encountered, the ascent became easier, until at length we found ourselves on the broad ridge between Kushigamine and Akahani. Just then the mist fortunately cleared and we had a fine view of the craggy flank of Ōbandai, the plateau of Numanotaira, and the sharp edge of the new crater. In wandering over this region, we were struck by many appearances which do not seem to have received from the earlier visitors the attention they deserved. This we think is a misfortune; for our observations, made ten months after the eruption took place, were necessarily incomplete.

It was abundantly evident, for example, that the forests to the east and south-east of Ōbandai-san had been subjected, not merely to a hurricane of wind, but also to a fierce cannonading of stones of all sizes from the tiniest grains to huge blocks. It may be safely said that the chief damage was due to this "hail-storm" of rocks and rubbish rather than to the wind, however strong that may have been. When the crest of Kobandai burst there were three main directions in which the fragments were hurled, namely northward, upward, and south-eastward. The south-eastward stream poured like a nearly horizontal hail-storm across Numanotoira, over the bounding ridge, and down the Biwa-sawa. The trees on the ridge and the neighbouring slopes of Akahani and Kushigamine were shattered, uprooted, felled, by this awful cannonading; but the cloud of stones, largely unchecked in their on-rush, shot over the ridge and down the steep slopes till the smaller gradients and their own accumulation brought them to a stand. Thus it is not surprising that no very thick deposit of new material is found at the higher levels. Much of the

dust and many of the smaller fragments, retarded by the viscosity of the air, would no doubt settle; but the vast majority of the larger fragments would continue their headlong rush down to lower levels. The great accumulations of rocks and earth at these lower levels do not necessarily imply the the horizontal hail-storm we have been picturing. The matter might have been launched *over* the ridge at a considerable elevation. But that much of it was really launched horizontally so as to graze the surfaces of the ridge and high level slopes is demonstrated by the nature of the damage done to the trees. As already mentioned, many of the shattered stumps are left still rooted to the ground. These are all barked on the side facing the crater, and scarred and cut and torn in a way that mere wind could never explain. It is not possible, of course, to separate the mere wind effect from that due to the solid driven matter; but we think it necessary to emphasise the latter much more strongly than appears to have been done in any of the earlier descriptions of the catastrophe. To get some idea as to the heaviness of this bombardment, we counted the separate cuts and bruises on the quarter of a square foot of the surface of a battered tree. The tree was chosen as a fairly representative one. A first rough reckoning gave 50 distinct hacks; and a second more careful count gave 75. That is, a square foot of this tree was, *after the bark had been peeled off*, subjected to a bombardment of at last 300 missiles to the square foot. This number must evidently be less than the total number in the shower and we may, without making any extravagant demands assume that across every square foot of vertical area between Kushigamine and Akahagi 500 good sized fragments swept, probably with a speed comparable to the muzzle velocity of a rifle ball. Small wonder that after such a storm had passed it should have left such devastation in its track! The horizontal projection of a cloud of solid particles of the kind pictured was no doubt accompanied by a fierce gust of wind; but there really seems to have occurred nothing indicative of anything

very extraordinary in this gust. By far the greater damage must be attributed to the horizontal hailstorm of rocks, stones, and solid fragments of all sizes from huge blocks to sand. The havoc was most complete on the eastern ridge of Numanotaira.* This is quite what we should expect. For the great velocity of projection of the rocky fragments would very quickly be cut down by the resistance of the air, even if no other impediments existed. The smaller particles would be retarded more quickly and would then act as a brake on the larger ones; so that in all probability the original energy of projection would have been almost entirely spent before the cloud of rubbish had reached the lower slopes. Just above Miné, the fragments were still able to indent the bark, but not to pull it off. In its descent, either through the air or down the steep slopes of the hills, the projected matter was of course aided by gravity.

To sum up the evidence, we see, from the character of the damage done to the trees on the upper ridges, that the shattered eastern flank of Kobandai was projected to a large extent horizontally, grazing the higher flats of Numanotaira, and mowing down the forests that grew there. The high speed of projection carried nearly all the fragments and dust quite over these regions into the ravines and valleys far below. As the *débris* descended it swept avalanche-like down the higher slopes which were too steep to give it a resting place, clearing them also of much of their vegetation.

In emphasising the effect of this horizontal rush of rocky fragments, we do not in any way mean to discredit the effects of matter projected at higher inclinations. There is no reason, however, to suppose that the vertical projection was denser than the horizontal; and there are good reasons for supposing that the horizontal was the greater. Or, to put it more accurately, the amount of matter projected at lower

* We leave out of consideration the regions now hid from view by the accumulated new material.

inclinations than 45° to the horizontal far exceeded the amount projected at higher inclinations. The particular manner in which the shattered mountain has re-distributed itself goes far to prove this. Thus there are certain regions in the vicinity of the new crater which have completely escaped any damage whatever; and there are other regions in which the damage done is comparatively slight. These lie to the north-east in the direction of Kushigamine, to the south in the direction of Obandai, and to the west. Of these, the first-named is perhaps the most remarkable, since it is wedged in between the great northern outburst towards Hibara and the south-eastern outburst towards Miné. Now in all these cases it is quite clear that the summits of Kushigamine, Akahani, Ōbandai, and the north-west ridge of the last, simply stopped the material from going in these directions. But very moderate upward inclinations combined with sufficient velocities of projection would have carried large blocks over these peaks and landed them on the further slopes. But no such blocks have been seen. In some parts *holes* have been found which have generally been regarded as having been made by falling stones. But in the regions we have specified these holes are not very numerous; and none have been found beyond Kushigamine or immediately to the south of Obandai. Assuming then that these holes were really caused by falling stones, originally projected at high inclinations from Kobandai, we must conclude that such stones were comparatively few in number. That no stones were hurled over Kushigamine shows that either the inclinations were insufficient or the velocities were insufficient, or that the eruption was singularly partial as to the directions of its out-burst. As an explanation of this apparent partiality, some have suggested the drifting action of the wind. Excepting, however, the local displacements of air which necessarily accompanied the avalanches of rock and rubbish, and which therefore cannot for a moment be regarded as giving direction to its own cause, the general drift of wind was from W.N.W. as proved by the

well marked track of the fine dust and ashes. If such a wind had any sifting effect upon the heavier particles, it could not in any imaginable way cause the stones projected nearly eastwards towards Kushigamine to deviate appreciably from their original course.

In fact, the more the features of the eruption are considered, the more is one impressed with the fact that as, regards the larger fragments, the outburst was mainly a horizontal one, or (more accurately) confined to inclinations less than 30° to the horizontal. No doubt along with the ascending cloud of dust, smoke, and steam, fairly sized blocks of stone were projected at higher inclinations; but they must have been comparatively few in number, and their speeds of projection by no means great. Only in that way can we give a really plausible explanation of the immunity from damage of the very near region lying just beyond Kushigamine, and the part to the south of Ōbandai.

Although the great outburst took place to the north, very little can be gathered from it as to the details of the explosion. All we see there is a great spread of *débris* quite covering up whatever particular damage may have been done to the former surface.

With regard to the smaller outburst to the south-east along and down the Biwasawa, it is otherwise. There we can trace the course of the great blast of shattered rock and disintegrated soil right across the flats of Numanotaira. Trees have been fiercely battered by the irresistible cannonading; have been bent to the blast, twisted, stripped bare, barked on the "wind ward" side, broken, felled, uprooted, hurled along, and many no doubt swept down the steep slopes and buried fathoms deep below the rubbish. To this day all possible kinds of devastation can be studied in the shattered remnant of the blasted forest. All over the region of the once dense forest, a vast number of holes are still to be seen, very much as they were seen by the earlier observers. No doubt rains have had

their usual denuding effects; but again the winter snows on the upper flats must have tended to preserve the original contour. These holes we believe to be mainly, if not entirely, the result of the uprooting of trees; the smaller holes being due to the uprooting of single trees, the larger ones possibly to the simultaneous uprooting of a clump of trees whose roots were more or less interlaced. That this is a sufficient explanation of many holes is admitted by Mr. Odlum in his paper, "How were the Cone-shaped Holes on Bandai-san formed?"—a paper, however, which was written avowedly with the object of proving that the conical holes were formed by falling stones. From what has been said above regarding the character of the outburst towards Miné, it will probably be readily recognised that many of these uprooted trees are to be sought for, not in the vicinity of the holes, but far below, buried deep in the accumulated *débris*.

As the very widely accepted theory of the formation of the conical holes through the agency of falling stones ejected from the crater has not been as yet critically examined in print, we propose here to consider it as fully as opportunity may permit. As Mr. Odlum's observations are the most complete on the subject, and as his paper has been already published in these Transactions, many of our remarks will naturally be suggested by his statements.

III.—The Conical Holes at Bandai-san.

It must be noticed at the very outset that the holes are not all of one class; and it appears to us, writing ten months after date, that the earlier observers did not pay sufficient attention to this. Leaving one of account the beautiful conical holes formed in the crater by the action of fumaroles, we are able to distinguish three kinds of holes in the vicinity of Bandai. These are sufficiently differentiated by the names conical, cylindrical, and flat basin-shaped. The conical holes abound in the devastated region to the east and south-east of Ōbandai. The other kinds are not by any means so numerous, and are

chiefly to be found to the W.N.W. of Ōbandai in the neighbourhood of Kaminoyu. These last are what have been observed by the great majority of visitors to the mountain, since they lie near the path which leads from Inawashiro to the great crater.

That falling stones can make holes in the ground is no doubt a fact of experience. But when we are asked to believe ‡ that stones can make holes of 30 feet diameter and 10 feet depth, or even 10 feet diameter and 3 feet depth, and bury themselves to a further depth of at least 3 feet below the apparent bottom of the hole, we are compelled to demand at the hands of the supporters of such a view the most complete proofs. We shall consider later the so-called proofs which have been advanced in support of the falling-stone theory. We shall first, however, discuss the problem of the falling body generally, to see what kind of effect we may reasonably expect to obtain when a large stone falls to earth with a reasonable speed. The problem, we believe, has never been discussed even approximately, that is, taking into account all the conditions. It is no mere question of a uniform acceleration with which we have to deal. When once we obtain speeds of several hundred feet per second, we bring into play an atmospheric resistance of a magnitude quite comparable to the weight of the falling body. Indeed, we shall see that for any reasonable case, it is really impossible for a falling body to attain a velocity of 1,000 feet per second. The reason simply is that if a body were descending near the earth's surface with such a speed, the retardation due to atmospheric resistance would exceed the acceleration due to gravity, and the speed would tend to diminish.

Even at moderate speeds the retarding effects of atmospheric resistance on falling bodies are quite appreciable. Thus if a cannon ball and a roughly cubical stone are dropped simultaneously from a height of 50 feet, the ball is dis-

‡ See Mr. Odlum's paper in this volume (p. 28); also Professors Sekiya and Kikuchi's paper in the same (p. 169).

tinctly observed to gain upon the stone and reach the ground ahead of it. Suppose the gain is half a foot; and suppose further that because of its form and relative mass the stone experiences an atmospherie resistance twice that experienced by the ball; then a simple calculation gives for the average acceleration due to the viscosity of the air the value 3 (ft. sec.$^{-2}$). We shall see immediately that this is a fair approximation to the value, as inferred from experiments on the flight of projectiles. It is, indeed, only from the very elaborate experiments in gunnery that we can obtain any definite ideas as to the magnitude of the atmosphere's resistance. Scientific Artillerymen have prepared valuable tables embodying the results of their experiments; and we shall base all our calculations on one of these tables. The full table will be found in the article *Gunnery* in the *Encyclopaedia Britannica* (ninth edition); it is sufficient for our present purpose to use it in a condensed form. In Table I.

TABLE I.

Speed in Feet per Seconds.	Space in Feet.	Time in Seconds.
400	5,000	5·000
500	8,701	13·306
600	11,702	18·796
700	14,280	22·781
800	16,513	25·769
900	18,362	27·954
1,000	19,843	29·521
1,100	20,898	30·531
1,200	21,592	31·137
1,300	22,179	31·607
1,400	22,693	31·988
1,500	23,162	32·312
1,600	23,607	32·599
1,700	24,033	32·858
1,800	24,441	33·091
1,900	24,832	33·303
2,000	25,207	33·496
2,100	25,556	33·666
2,200	25,876	33·816
2,300	26,174	33·948
2,400	26,446	34·064
2,500	26,696	34·166

there are three columns headed speed, space, and time; and these are so related that if any two sets be taken, the difference of the time numbers represents the interval during which the speed of a particular kind of projectile will be reduced from the higher to the lower value, and the difference of the space numbers represents the space described. Thus, as an example, the projectile moving horizontally in air with a speed of 2,000 feet per second will have its speed reduced to 1,000 in 3·995 seconds, during which interval it will have travelled 5,364 feet. The particular projectile for which this table is constructed is an ogival headed projectile, whose mass in pounds is equal to the square of its diameter in inches. Now for similarly shaped projectiles, the resistance of the air varies directly as the square of the diameter and inversely as the mass. Hence, if d is the diameter and w the mass in pounds of any other ogival projectile, the number d^2/w will give the ratio of the average resistance experienced by this projectile to that experienced by the former in reducing the speeds of each from one given value to any other given value. If d^2/w is less than unity, the projectile will travel proportionately further between two given limiting values of speed.

Besides the relation between the size and mass of a projectile, another very important point is the shape. Thus according to Bashforth's tables the resistance experienced by a spherical shot varies, according as the speed is high or low, from 1.5 to 2 times the resistance experienced by an ogival headed projectile of equal weight and diameter. Then experiments have also proved that at tolerably high speeds, a flat-headed cylinder experiences a resistance about 2½ times that experienced by the ogival headed cylinder. For lower speeds, say under 1,000 feet per second, the resistance experienced by the flat headed cylinder will in all probability be proportionally greater, as in the case of the sphere. Now a rough shapeless stone cannot possibly be less resisted than a smooth flat-headed cylinder, especially if, as is almost certain to be the case, the stone is also rotating. We are probably well within the mark if we

consider the resistance experienced by a rough shaped stone to be three times that experienced by an ogival projectile of the same weight and of cross-section equal to the mean cross-section of the stone.

Again it should be pointed out that, in applying to the case of a large stone numbers that have been obtained by experiments on comparatively small projectiles, we are making the assumption that the resistance is directly proportional to the surface, other things being equal. But this law, true though experiment shows it to be for a limited range of dimensions, can hardly be expected to hold accurately when we compare say a 7 inch sphere with a 3 feet or 36 inch spherical shell of the same mass. When the nature of the dynamical process by which such a mass pushes its way through air is considered, it will probably be granted that the resistance increases somewhat more rapidly than the surface when the surface becomes very large. Taking all the conditions of the case into account, we are convinced that, in the calculations now to be presented, we are really underestimating the resistance experienced by a rough shaped stone as it travels through the air.

To fix our ideas, we shall calculate in detail various problems in connection with a stone of the size and weight of one of those described by Mr. Odlum. He gives 27 by 35 by 40 inches as the dimensions of a stone excavated by him out of one of the so-called conical holes. We may take as comparable with this a projectile of area equal to 36^2 square inches; and we shall certainly be underestimating the effects of atmospheric resistance if we regard this projectile, assumed cylindrical, as experiencing a resistance three times as great as that experienced by an ogival projectile of the same diameter and mass. The diameter corresponding to the above area is $\sqrt{1648}$; and the mass, as estimated by Mr. Odlum, is 3,975lbs. Hence the number d^2/w is 0.46; and multiplying by 3, we find 1.38 as the factor to be used in deducing from the numbers given in Table I. the numbers which may be supposed to be applicable to the case in point.

The simplest way to do this is to form a second table (Table II.), in which are entered the average accelerations corresponding to given speed limits. The operation consists simply in taking the first differences of the columns of Table I. and in dividing the change of speed or total acceleration by the corresponding interval of time. In Table II. the first column gives the limiting speeds; the second, the interval of time during which the resistance of the air reduces the speed from the higher to the lower limit; the third, the average acceleration produced by this resistance in the case of the ogival projectile for which $d^2=w$; the fourth, the same for the stone under discussion. The values for speeds less than 400 are estimated by a rough interpolation:—

TABLE II.

Limiting speeds in hundreds of feet.	Interval of time in seconds.	Average acceleration (ft. sec²) Ogival.	Irregular.
25-24	0·102	—980	—1352
24-23	0·116	—862	—1190
23-22	0·132	—758	—1046
22-21	0·150	—667	— 920
21-20	0·170	—588	— 811
20-19	0·193	—518	— 715
19-18	0·212	—472	— 651
18-17	0·233	—429	— 592
17-16	0·259	—386	— 537
16-15	0·287	—348	— 480
15-14	0·324	—309	— 426
14-13	0·381	—262	— 362
13-12	0·470	—213	— 294
12-11	0·606	—165	— 228
11-10	1·010	— 99·6	— 137
10-9	1·567	— 64·0	— 88·3
9-8	2·185	— 45·8	— 63·2
8-7	2·988	— 33·4	— 46·1
7-6	3·985	— 25·1	— 34·6
6-5	5·490	— 18·2	— 25
5-4	8·306	— 12·0	— 16·6
4-3	——	— 8	— 11
3-2	——	— 5	— 6·9
2-1	——	— 3	— 4·2
1-0	——	— 1	— 1·4

The numbers in the third column are obtained from those

in the second by dividing 100 by each of the latter; and the numbers in the fourth column are obtained from those in the third by multiplying by 1·38.

In applying these numbers to any problem involving vertical motion, we must calculate at each step the combined effects of gravitation and atmospheric resistance. When the body is ascending, the resistance due to the air acts with gravity; whereas when the body is descending, the resistance due to the air acts against gravity.

Consider first an ascending body whose speed is reduced in time t from v to $(v-100)$. By gravity, the total acceleration in this time is $-g\,t$; and by resistance due to the air the total acceleration is $-a\,t$, where a is the number in Table II. corresponding to the limiting speeds v and $(v-100)$. Hence the total acceleration due to both combined is $-(g+a)t$, and this must be equal to -100. Thus we find for the interval of time during which v is reduced to $(v-100)$, the expression

$$t = \frac{100}{g+a}$$

From this we find for the space described the approximate value

$$s = t\,(v - 50)$$

being the time multiplied by the average speed.

If the body is descending we must change the sign of a in the expression of t, or

$$t = \frac{100}{g-a}$$

In applying this formula we must confine ourselves to cases for which a is numerically less than g. Thus we see at a glance that it is impossible for an ogival shaped projectile to attain *by merely falling* a higher speed than 800 feet per second, or for an irregularly shaped mass to attain similarly a higher speed than 700 feet per second, however far each is allowed to fall.

The numbers given in Tables I. and II. hold only for the motion of projectiles in air at the ordinary pressure at the sea-level. Obviously at great heights the pressure and density of the air will be so diminished as to give rise to a resistance distinctly smaller than that experienced at low elevations. Exactly how the resistance to high speeds varies with the density of the air is not known; but we may here assume for the purposes of calculation that it varies in direct ratio. Thus at a height of 10,600 feet, the retardation due to atmospheric resistance experienced by our irregular body moving with a speed by 1,050 feet per second will be, not 137 as given in Table II. but 91—these two numbers being in the ratio of the pressures at the sea-level and at the height named. This correction for decrease of atmospheric resistance due to increase in height must be applied to every particular case.

Let us then take this problem as one directly comparable with what may have occurred at the Bandai-san eruption. A rough flat headed body 36^2 square inches in area and 3,975 lb. in mass is projected upwards from a height of 8,000 feet with an vertical speed of 2,500 feet per second. To what height will it ascend, and with what speed will it come to earth at any named elevation?

The first part of the problem is completely solved in Table III., and the second part in Table IV. Both of these tables are constructed on the same principle by means of the numbers given in the last column of Table II. The first column contains the limiting speeds in hundreds of feet; the second, the interval during which, at the assumed height, the particular change of speed takes place; the third, the space described during the interval in question; and the fourth, the total space described from the beginning to the end of the said interval:—

Table III.

Limiting speeds in hundreds of feet.	Interval in seconds.	Space described in interval.	Space described from the beginning.
25-24	·099	242	242
24-23	·113	265	507
23-22	·128	288	795
22-21	·147	312	1,107
21-20	·166	341	1,448
20-19	·191	372	1,820
19-18	·211	391	2,211
18-17	·234	410	2,621
17-16	·259	428	3,049
16-15	·291	452	3,501
15-14	·331	480	3,981
14-13	·386	522	4,503
13-12	·472	590	5,093
12-11	·588	675	5,768
11-10	·893	940	6,708
10-9	1·220	1,160	7,868
9-8	1·515	1,280	9,148
8-7	1·79	1,330	10,478
7-6	2·04	1,320	11,798
6-5	2·33	1,220	13,018
5-4	2·56	1,150	14,168
4-3	2·78	275	15,143
3-2	2·94	740	15,883
2-1	3·00	450	16,333
1-0	3·07	150	16,483

Table IV.

Limiting speeds in hundreds of feet.	Interval in seconds.	Space described in interval.	Space described from the beginning.
0-1	3·17	160	160
1-2	3·28	492	652
2-3	3·37	843	1,495
3-4	3·66	1,280	2,775
4-5	4·08	1,841	4,616
5-6	5·03	2,766	7,382
6-7	8·55	5,558	12,940
7-7·1	2·08	1,470	14,410
7·1-7·2	3·85	2,750	17,160

The mode in which these tables have been constructed will be made clear by working out a particular case in each.

Thus, to find the interval during which the ascending stone has its speed reduced from 1,100 to 1,000 feet per second,

take from the last column of Table II. the number 137 corresponding to the said limiting speeds. This measures the negative acceleration due to the resistance of the air at ordinary sea-level pressure. But we know from the previous part of Table III. that the stone has ascended 5,768 feet, so that its mean height during the next interval will be about 14,000 feet (8,000 + 6,000) above sea-level. Hence the density of the air will be less than the density at sea-level in the ratio of approximately 17·51 to 30. Reduce 137 in this ratio, add 32 (or g) to it, and the result, 112 namely, will be the measure of negative acceleration acting on the stone. Divide 100, the total change of speed, by this number, and the quotient ·893 is the corresponding interval as given in the second column of Table II. This interval, multiplied by 1,050, the average speed, gives 940 as the corresponding space described; and this, added to 5,768, gives 6,701, the total space described from the beginning of the motion. In this way, step by step, the final column of Table III. has been deduced.

Then, again, to find the interval during which the stone in its descent has its speed increased from 600 to 700 feet per second, take from the last column of Table II. the number 34·6. But already the stone has descended 7,382 feet, and is therefore at a height of 17,101 feet. Before the speed can attain to 700 feet per second, the body will have to fall some 6,000 feet further. Hence we may apply to the number 34·6 the correction due to the density of the air at a height of 14,000 (16,000—3,000) feet. That is, we multiply 34·6 by the factor 17·6/30 and obtain 20·3. Thence we deduce 11·7 as the downward acceleration acting on the body, and 8·55 seconds as the interval during which the speed is increased by 100 feet per second. The space described in the interval is at once found by multiplying the time by the average speed, and this added to 7,382 gives 12,840 feet as the total space described since the beginning. After this condition is reached, the speed is accelerated

more and more slowly as the body falls to lower levels. The two last rows of numbers in Table IV. are calculated for total accelerations of 10 feet per second at a time—the factors being obtained from Table III. by rough interpolation. We thus see that the mass, originally projected with a velocity of 2,500 feet per second, returns to the assumed level of its point of projection with a speed of barely 720 feet per second; and further, a consideration of the numbers in Table III. will show that, in descending to lower levels, even to the sea-level, the mass will suffer no appreciable increase of speed.

Thus a fair-sized block of 4,000 lb., projected from a height of 8,000 feet above the sea level with a vertical speed of 2,500 feet per second, will reach a height of 24,500 feet above the sea-level. It will return to earth from that height with a speed of 720 feet per second; and it will have nearly attained this speed after it has fallen about half that height.

The amount of energy lost during the ascent is 324 million foot-pounds, and the energy lost in the descent to the level from which the body was projected is nearly 63 million foot-pounds. This gives a total loss of 387 million foot-pounds of energy out of an original 390 million foot-pounds. Much the same loss of energy will occur in the case of a body projected with a high speed horizontally at low elevations. A large part of this loss of energy will appear as heat in the stone itself. If we suppose one-third of it to be so transformed, and assume the specific heat of the stone to be 0·2, the temperature of the 4,000 lb. block will be raised by fully 200° Fahrenheit. The hot particles felt by some of the sufferers are thus fully accounted for.

Although it has no particular bearing on the subject under discussion, an interesting calculation may be made as to the speed with which the same stone would reach the earth if projected from a height of 24,000 feet with an initial downward speed of 2,500 feet per second. By the time it had fallen half way, its speed would be diminished to 1,000 feet per second;

and it would come to earth with a speed of about 800 feet per second. This sufficiently explains the comparatively low speeds with which meteors reach the earth. Also since any initial horizontal or (more accurately), tangential speed will be cut down by the atmospheric resistance without being at all sustained by any other force, we see that such a meteoric stone will come to earth in a direction not much inclined to the vertical.

The foregoing calculations then lead to the conclusion that 700 feet per second is as much speed as an irregular cube-shaped stone 4,000 pounds weight, and one square yard in section, can be expected to attain by merely falling from any height, up to the practical limits of the earth's atmosphere at any rate. The next question to discuss is, what penetrating power can this stone, reaching the earth with such a velocity, be reasonably expected to have? From observation we know that a good sized meteoric stone can do little more than bury itself; and, in the absence of unquestionable evidence to the contrary we have no right to endow a stone projected from a volcano with any very superior powers. Here again, however, we shall appeal to the experiments of artillerymen.

In Chapter VI. of Bashforth's Motion of Projectiles (1873), Didion's constants for the calculation of the penetration of spherical shot into various kinds of woods, earths, and masonry, are given in English measures, together with the formula that gives the depth penetrated in terms of the striking velocity. From these data the following table has been calculated, giving for different velocities the penetrations in feet of a spherical shot, whose weight in pounds is equal to the square of its diameter in inches.

The first column contains the name of the substance penetrated, the other three columns contain the depths in feet to which the shot penetrates, and at the head of each of these three columns is the corresponding striking velocity in feet per second:—

Substance penetrated.	Depths penetrated for Striking Velocities of 1,000.	750.	500.
Oak, Birch, and Ash	3·76	2·57	1·36
Elm	4·89	3·33	1·77
Fir and Birch	7·04	4·80	2·55
Poplar	7·19	4·90	2·61
Sand, mixed with gravel	5·12	4·19	2·97
Earth, mixed with sand and gravel	3·72	3·05	2·17
Clayey soil	5·87	4·22	2·43
Old Parapet Earth	6·70	5·05	3·10
Damp clay	15·00	11·55	7·38
Moistened clay	43·52	33·52	21·4
Good masonry	1·51	1·05	0·54
Medium masonry	1·97	1·31	0·68
Brickwork	2·75	1·83	0·95

The object of the experiments on which these numbers are based was of course a very practical one, being nothing else than the investigation of the resisting power to bombardment of different kinds of defensive structures. The earths were therefore all "prepared" and cannot possibly have been more resisting than natural solid earth full of stones of all sizes and knit together by grass and tree roots. We are therefore quite warranted in regarding 4 feet as a superior limit to the penetration in natural earth of such a shot falling with an impact speed of 750 feet per second.

Hence a smooth spherical ball of the same weight and the same cross-section as Mr. Odlum's stone above described would penetrate (4/0·46=) 9 feet nearly. In penetrating power, an ogival headed projectile is distinctly superior to a sphere of equal diameter and weight, in a ratio not smaller than 3 to 2. We may reasonably suppose a cube or flat headed cylinder to have still less penetrating power in earth, as we have shown them to have in air. With the fair enough assumption, then, that a rough cuboid block experiences 3 times the resistance which an ogival headed projectile experiences, we find 4½ feet as the superior limit of depth to which a rough hewn stone of the size and mass described will penetrate.

In this discussion, the one step of any doubt is the last. It

will certainly be admitted, however, by any capable of giving the matter scientific consideration that a rough cuboid will have distinctly less penetrating power than a smooth sphere. We have unfortunately no experiments to guide us to a definite understanding of the matter. Experiment would be difficult, indeed; for even were stones dropped from the top of an Eiffel Tower, they would reach the ground with a comparating low speed of some 200 feet per second. Still in such experiments, the results would be valuable as establishing comparative penetrating powers of masses of different shapes and sizes. Experiments with stones dropped from ordinary heights are worthless, as we found ourselves by trial. The stones were in many cases only half or even quarter buried, and it was not possible to estimate even approximately what might be called the average section.

Guided by the discussion just given and by a general consideration of the character of holes made by projectiles, we may safely sum up our conclusions thus:—

1. If a stone falls with sufficient speed to make it really bury itself beneath the original surface of the ground, it will form a cylindrical hole of a diameter a little greater than its own. A "conical" appearance may then be given to the hole either by the falling in of small ashes and dust following in the wake of the stone. The latter is highly probable in the case of an eruption like that which happened at Bandai-san; the former is very unlikely to take place in old vegetable-bearing soil. Now, in the Nakanoyu region to the west of Bandai-san, such cylindrical holes of comparatively small diameter were seen both by the earlier observers and by ourselves. The diagram shown in Professors Sekiya and Kikuchi's paper (p. 167 of this volume) evidently represents such a possible hole. It is believed by them to have been made by a cuboidal stone half a metre each way. Assuming this stone to be of the same density as Mr. Odlum's stone for which we have made detailed calculations, we readily see

that its penetrating power for a given speed will be a little more than half as much. Thus, even if we grant to it all the penetrating power of a smooth sphere of equal weight and cross section, we should not get it to penetrate deeper than 5 feet. In this conclusion we are in fair accord with Sekiya and Kikuchi's own rather vague calculation. They say, "The velocity needed for penetrating a soft loamy soil to a depth of 2.5 metres would be between 300 metres and 600 metres per second, according to the value of coefficients we take." Here we are left in complete darkness as to what will penetrate that depth with that speed—is it an ogival headed projectile, or a cannon ball? Still, taking the mean of these two speeds, namely, 450 metres or 1,480 feet per second, and calculating from Bashforth's formula and table for clayey soil, we find that a ball whose weight in pounds is equal to the square of its diameter in inches will penetrate 9 feet or 2.73 metres. But we absolutely deny that a stone falling in air can ever attain such a speed as 1,480 feet per second, even though it should fall from infinity; so that, in this particular case, we cannot follow Professors Sekiya and Kikuchi in believing that the hole as figured in their drawing was altogether formed by the stone that is shown resting at the bottom. But, although we are compelled to regard this as, to say the least, a doubtful case, we are quite prepared to admit that the comparatively small cylindrical holes that are pretty plentiful to the West of the mountain and which, be it noted, *were those chiefly seen by visitors*, were formed by falling stones. The holes described by Mr. Odlum can hardly, however, be included in this category, as we shall see further on.

2. If a stone falls with a moderate speed so as to be incapable of burying itself completely, it will probably produce a splash out of earth; and if, as is highly probable, it should be broken by the concussion, a shallow basin-shaped scar will be formed. Effects of this character were also observed in the Nakanoyu region. But it is difficult to regard the large coni-

cal holes described by Mr. Odlum as having been formed in this way. For according to his description (p. 28 of this volume) some of these holes are so large as to have required a very large boulder indeed to have produced them. But no such large boulder is described; and if it had broken into fragments, there would be fragments not only in the hole but all round it. But (p. 25 of this volume) there is nothing on which Mr. Odlum is more emphatic than the fact that in the region he is considering there are no stones to be found on the surface.

3. We believe that many of the holes described by Mr. Odlum cannot be sufficiently explained on the falling stone hypothesis. As Professors Sekiya and Kikuchi regard Mr. Odlum's researches as having settled the question of the origin of the comical holes, it will not be out of place here to consider the facts and proofs brought forward by him in support of his view. Mr. Odlum certainly deserves high commendation for the energetic way in which he carried out his labours. His facts, such of them as he gives, must be accepted as incontrovertible. It is unfortunate, however, that he has given such an incomplete statement of all that he must have observed. In the discussion which followed the delivery of his paper before the Seismological Society of Japan, one of us asked for distinct information on these points: (1) how many holes did he dig into, (2) how many of these contained new stones, (3) was there any relation between the size of the hole and the size of the stones found in it? No answer was given to these questions at the time; and it is with feelings of great disappointment that we search in vain through his paper for information on these important points.

Another important question suggested by our own visit there is, what was the former character of the region in which a given hole was found? Was it wooded, or was it grassy? In Mr. Odlum's paper there is no distinct statement even as to where he made his investigations. From his map we infer

that it was to the South East of the mountain, including the region we have described above in discussing the character of the outburst towards Miné. This particular region was, we believe, not visited by Professors Sekiya and Kikuchi; and it is very questionable whether arguments based on the appearances in one region are applicable to the somewhat different appearances seen in another region. One gentleman, who made a very complete survey of the Numanotaira plateau, formed the theory that the large holes there were produced by small local tornadoes. We mention this simply as an illustration of the difficulty some have had in crediting falling stones with such tremendous hole-producing powers. The simple fact seems to be that the vast majority of visitors contented themselves with visiting the crater by way of Nakanoyu and that very few indeed took the trouble of ascending to the higher slopes of Ōbandai, Akahani, and Kushigamine. They thus saw only the moderately-sized holes formed to the west and north-west of the crater; and, as these could easily be formed by falling stones, they hastily concluded that all the other reported holes were formed by the same agency. Mr. Odlum, however, seems to have confined his investigations solely to the region to the south-east of the crater; for here only are the large conical holes of 20 or 30 feet in diameter to be found.

Let us now take up Mr. Odlum's proofs in order. To his 1st Question, did stones fall? no one can of course hesitate to answer yes. Under his 2nd Question, where are these stones? there are some some statements calling for remark. Statement *A*. proves indirectly that Mr. Odlum is dealing with the region to the south-east; for here only do we find holes and no stones on the surface; but that "stones fell in all directions" is a remark that is hardly borne out by the evidence. No holes are found to the south over Ōbandai, and no holes are found to the east over Kushigamine. These facts are difficult to reconcile with a heavy vertical projection of the kind that

must be imagined if "tens or hundreds of thousands of holes" (see *D.*) are to explained as produced by falling stones. Kushigamine at any rate was a lower height than Kobandai; and it is difficult to believe that a heavy vertical outburst, which alone can give sufficient speeds for penetrating purposes, should have been so partial in its final distribution. In paragraph 21 (page 31) the author invokes the wind, which was blowing towards the E.S.E. at the time. But a "moderate northwesterly breeze," as it is characterized by Professors Sekiya and Kikuchi, could have very little drifting effect upon large masses; and besides Kushigamine lies in the very direction in which this wind was blowing. Mr. Odlum's assumption that the "wind at a great elevation was very strong," (p. 31, *A.*) is altogether gratuitous. His further suggestion* under heading *B* is an extraordinary example of making one of two co-existent effects the cause of the other. Under heading *C* on the same page, however, there is a very clear description of what in all probability actually took place. It quite falls in with our view of the largely horizontal character of the outburst towards Miné. Returning again to paragraph 2, we meet at once with another difficulty of distribution. It is distinctly laid down that no stones were found except in holes. Now it seems to us to be a great demand upon our credulity to be asked to believe that, granted a heavy vertical outburst, all the falling stones should have gone up so far as to have come down with speeds sufficient to enable them to penetrate considerable depths. Surely in such a case, in the region to the east of Numanotaira, stones of all sizes and shapes would be found strewn about. According to our view of the case, however, this lack of stones is easily explained. The outburst, occurring mainly at comparatively low elevations, carried nearly all the heavier fragments over the plateau and precipitated them down the slopes beyond. The whole forest

* In this page these are some obvious misprints of "north" for "south" and "N." for "S."

was devastated, and large numbers of trees carried bodily out of the ground. Into the holes formed by the uprooting of these trees, it is quite to be expected that some of the stones should fall and be more or less covered over with débris and loose soil. Mr. Odlum did not find stones in all the holes (see *E.*, page 25), which he explains in paragraph 13 (p. 28) on the hypothesis that these holes were holes made by people digging out pine-roots. Unfortunately, as already noticed, we get no information as to what proportion of the holes dug into were found to contain stones. The facts described under *F.* and *G.* are not inconsistent with what we have described as a probable explanation of the presence of stones in many of the holes; and the incidental information we get regarding the character of the soil, full of old roots and boulders, simply diminishes the likelihood of deep penetration. Paragraph 3 (p. 25) is much too vague in statement to lead to any certain conclusion; paragraph 4 proves nothing except that a stone hit a rock; while if paragraph 5 means anything, it means that the stone shown in Fig. II. was travelling horizontally and with a speed not by any means excessive.

In regard to the discussion of the forms and sizes of the holes, paragraphs 6 to 15, we may remark that the eccentric position of the stone in the hole proves only that the stone came into it obliquely and does not necessarily mean that the stone made the hole; that some of the arguments brought forward have no bearing on the question how were the holes formed (*e.g.*; 9, 10, 11); and that the discussion of what ought to be if Professor's Milne's theory were true is singularly pointless. On the other hand, in paragraph 8, Mr. Odlum brings forward a fact, which under certain conditions would be very difficult to explain on any other hypothesis than that of the falling stones. Under paragraph 14, more complete details regarding the admixture, so to speak, of large and small holes, would have been very desirable. In paragraph 15, Mr.

Odlum seems to say, that relatively to their diameters, the holes were shallower higher up the mountain than lower down; and this he explains by a difference of velocity. But, if stones went high enough so as to come to their original level again with sufficient speed to form large holes, we have seen that there will be very little acceleration as they fall an extra 4,000 feet. The relative shallowness of the higher holes seems to be sufficiently explained as due to greater density of ashes and dust that fell at the higher levels.

In paragraphs 16 and 18 we have some measurements given us, but strangely incomplete. Thus we are told the size and weight of one stone; but can gather nothing as to the size of the hole whence it was dug. Then we are given careful measurements of the dimensions of two holes; but not a hint as to the size of the stones found therein.

We have entered into a detailed criticism of Mr. Odlum's paper, since it has been made so much of by the supporters of the falling stone theory, and since he alone of all the many observers in the days immediately succeeding the eruption took the trouble to get at the facts. For such enthusiastic labour he deserves warm praise. But we doubt if he can be regarded as having established his case, that hundreds of thousands of holes to the South-east of Bandai-san were formed by falling stones. He seems to have been a little doubtful in his own mind as to the universal applicability of the theory he is striving to establish (see paragraph 20). In the early part of the paper he admits that many holes were formed by the uprooting of trees; but seems to expect that the uprooted tree would always be found lying near its hole. On the site of the devastated forest above the slopes of the Biwa-sawa we saw root stumps turned right up on end, often absolutely trunkless. Immediately after the eruption many of these torn up roots would be covered with fallen débris, and might easily escape the notice of investigators intent on the investigation of the holes. Our own impression is that sufficient attention has

not been given to the formation of holes by the uprooting of trees; and that, when this cause is taken into account and the effect of earthquake shocks in producing landslips is given its full weight, the holes left to be explained by the action of falling stones will by no means bulk so largely as a reader of the papers already published would be led to infer.

We do not claim to have brought forward an hypothesis that can apply to every reported case of a hole; we do not think that to be possible. Our object has been to criticize, in a scientific manner, the widely accepted theory that all the holes were formed by one agency, namely falling stones. Not a few scientific men, at the first statement of this theory, felt there were grave difficulties in the way of accepting it. By our discussion of the effect of atmosphere resistance in retarding a falling stone, and of the probable penetrating powers of such stones in ordinary soil, we have pointed out exactly what these difficulties are; and the more one considers the whole subject, the more is one impressed with the insurmountable character of these difficulties, and the less is one disposed to accept the unqualified conclusion of Professors Sekiya and Kikuchi.

The following communication on tbe origin of the Bandai-san notes was received from Dr. G. Wagener on January 12th, 1890:—

I visited Bandai-san for the first time on the 25th of August, 1889, in company with Mr. Janson, Professor at the Agricultural College of Komaba. Following the well known road from Inawashiro to Nakano-yu, and coming near this last place, we noticed some of the holes in question, 4 to 6 feet in diameter and 2 to 3 feet in depth. Mr. Janson's immediate impression was that these holes were exactly like those which could be seen by the thousand, all around Paris, during the siege in the Franco-German war. These latter holes, of the above diameter and deep enough to hide a man squatting down, were well-known to have been

made by the big shells thrown from the French forts against the German positions. These shells being mostly provided with time-fuzes, did not burst in the moment of striking the ground, and frequently did not burst at all. After having ricochetted perhaps several times, they had fallen flat upon the ground, as any spent cannon ball will do. There they were found, not at all inside of the holes, nor in their neighbourhood, but at places more or less distant from these holes. Such shells which had not burst, were laying about in such numbers, towards directions specially favoured by the French artillerists, that detachments of soldiers were sent out regularly to look for these shells and to bury them. This was done to prevent accidents in case cavalry or artillery advanced to meet a sortie, and should move over such ground strewn with shells. The holes made by the bursting of shells were entirely different in appearance from those made by ricochetting shells.

Dr. Kellner, Professor in Komaba, who also has been at the siege of Paris, not only confirms the above statement, but, having visited Bandai-san shortly after the explosion, is perfectly certain that the edge of the holes turned towards the crater, was much more sharply defined than the opposite side where by a ricochetting stone some sputtering must have occurred.

The similarity in the aspect of the holes around Paris and those on Bandai-san is so striking that both Prof. Kellner as well as Prof. Janson are of opinion that, if the gentlemen who are opponents to the hypothesis of falling stones had seen both kinds of holes they would not hesitate a moment to admit this explanation.

In the presence of the above facts and the absence of all evidence referring to the very act of originating the holes, it seems to be beyond doubt that there is no reason to reject altogether the theory of the falling stones. On the contrary, it is most probable that at least a number of the holes have been formed in this way. Whether all the holes, even the large ones of 20 and 30 feet in diameter, with depths proportional, have

been made by falling stones or not, I do not venture to decide, and perhaps would not venture even if I had seen them, which is not the case. But if there are holes quite different in size, in appearance, in locality, etc., from others, there is no necessity to maintain that the origin of all of them is due to one and the same cause.

Perhaps some opponent to the theory of the falling stones will make the objection that the circumstances of the fall of the Paris shells and of the Bandai-stones are not the same, in so far as both struck the ground under very different angles. The distance at which the Paris shells were throw, was five English miles and even beyond 6 miles. For such distances, the elevation of the fixing guns must have been very considerable. I have no tables to refer to, but I think, an elevation of 30° to 35° is a low estimation. It is well known that the second half of a trajectory, chiefly of such a long one covering a horizontal distance of 5 to 6 English miles, is considerably steeper than the first half or than the elevation of the gun; and we may well admit that the Paris shells struck the horizontal ground under an angle, say of 50°, or even more. In the case of the Bandai-san, the holes are mostly found on the slope of the mountain. If not, and if of quite a peculiar nature, they may, as I said before, have been formed by some other cause than falling stones. Suppose a stone having been thrown out of the crater, and coming down at a very steep angle, say 70° to 75°; if it falls upon the slope of the mountain at a place where the incline is 20° to 25°, it will, just like the shells, strike the ground under an angle of 50°, make a hole and ricochet once or twice or more as the case may be. I do not think that my figures have been chosen thus as to make me incur the reproach of having forced my argument. At all events, any objection not based upon positive ballistic facts and experiments referring to similar circumstances of trajectories and ground as on Bandai-san, would be insufficient to outweigh the matter of fact statements made in the beginning of this letter.

There is a way, very simple—I do not say easy and comfortable—of ascertaining whether the foregoing explanations are to be point or not, that is to look for stones or boulders not inside, but outside of the holes, at places much lower down. Anyone who has amused himself in his youth to roll big stones down the slope of a hill, knows what tremendous bounds they make, carrying obstacles like small brushwood easily before them and stopping only at far away distances even if the gradient is gentle. Isolated stones or boulders may be found on Bandai-san down the slope below the holes, and their nature will show whether they have come from the crater or from somewhere else. That boulders have been thrown far away, there can be no doubt. Any visitor to Naka-no-yu can see evidences of a big boulder having been thrown against the slope of Masu-yama. It laid bare the rocky ground, and broke into several pieces, which slid down to the bottom of the slope where they are now lying.

[Note added April 28th, 1890.—Dr. Wagener's interesting communication suggests ricochetting stones as a sufficient cause of the smaller sized holes. He expressly guards himself, however, against extending such an explanation to the very large sized holes. His views therefore can hardly be regarded as antagonistic to those expressed in the foregoing paper. It will suffice to point out that, even with the modification suggested by Dr. Wagener, the chief difficulties still remain as regards the numerous holes to the south-east of Kobandai. Thus their very number is a difficulty; for if they were all formed by ricochetting stones that then hurled themselves down the slopes, these stones must have been so numerous that it is difficult to imagine many of them not getting stranded in the higher flats.—C. G. K.]

Plate I.

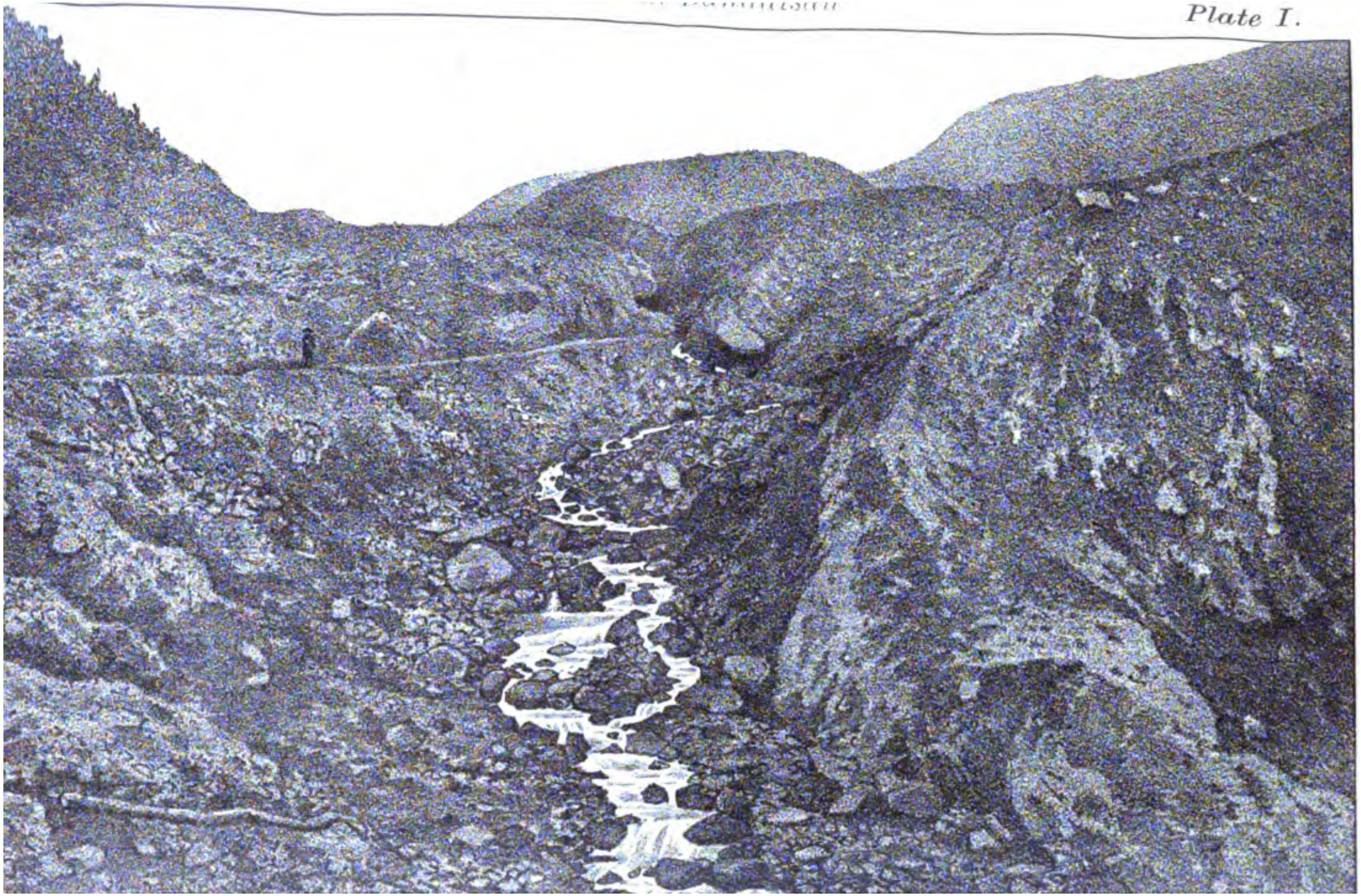
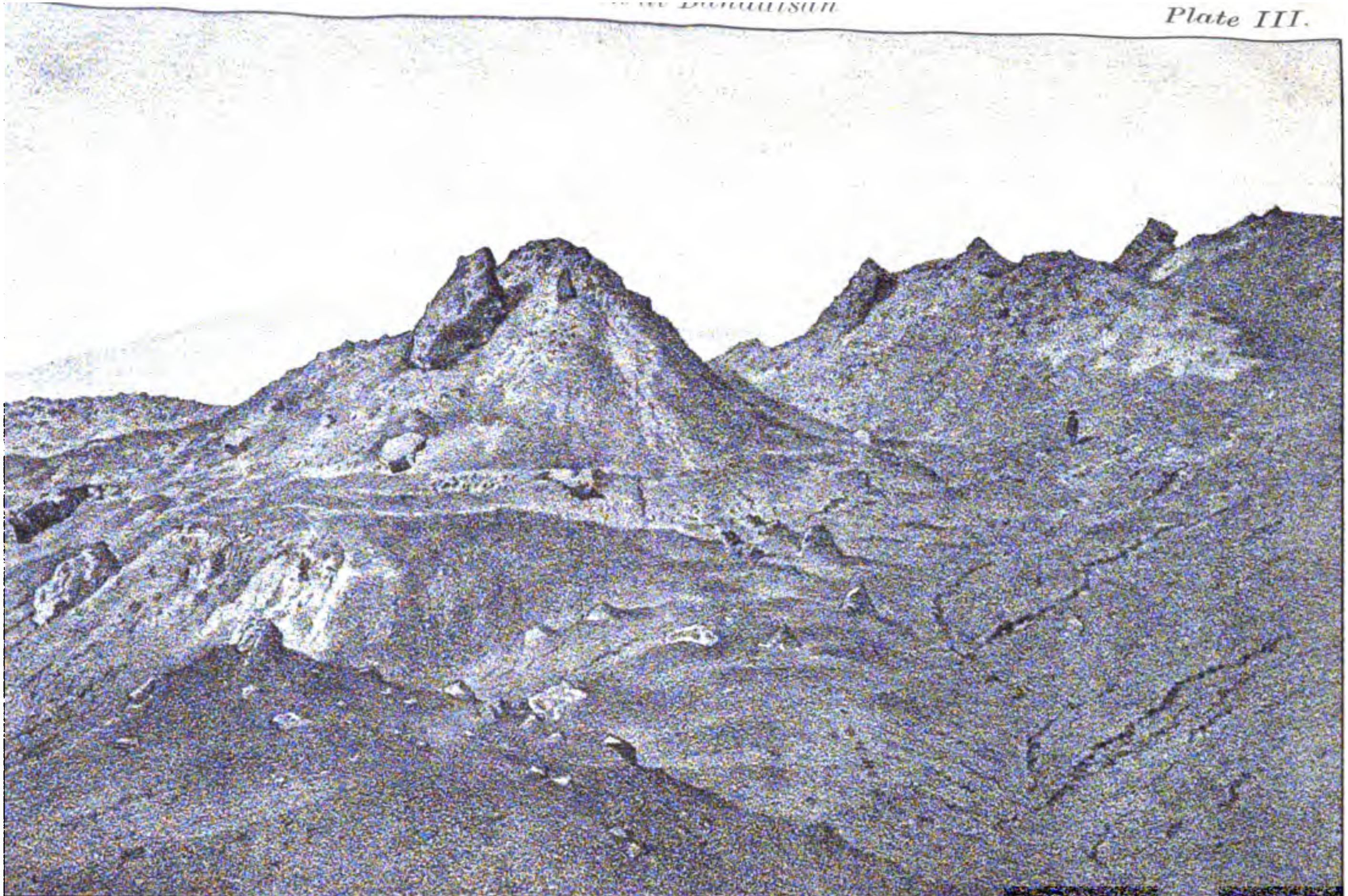


Plate III.



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